INSTRUCTION

M A N U A L

PC BASED THERMOLUMINESCENCE ANALYSER SYSTEM INTEGRAL

TYPE : TL 1009I

NUCLEONIX SYSTEMS PRIVATE LIMITED

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File Name : TL1009I _Man
Date : 09-04-2015

NOTE TO USERS

Users are advised to refer to SYSTEM HARDWARE REFERENCE MANUAL for understanding hardware part of the system, its constituent units, system integration and its functioning.

Also by refering to this manual, user will know how to unpack, assemble, interconnect / integrate the complete system, for use and operation.

SYSTEM SOFTWARE COMMANDS REFERENCE MANUAL is to be referred for using and operating the system under P.C. controlled mode. Also for TL glow curve acquisition, analysis and processing.

Important Notes

System performance is guaranteed only if a good 2KVA servo stabilizer is used. A highly stable, supply 230V, AC is essential. Do not use the system without servo stabilizer. Also good earthing is to be ensured.

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1.SYSTEM HARDWARE INSTRUCTION MANUAL

SYSTEM HARDWARE INSTRUCTIONMANUAL

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UNPACKING

Please read the following lines and observe precautions, while unpacking the system. Unpack each box gently & avoid hammering & hard hitting.

1. Usually the system is packed in card board/ wooden boxes.

2.

	Equipment Packed Usually	**Quantity**	
a.	CPU Unit of Personal Computer (Optional)	One Box	(units (a), (b) & (c) are supplied, only if the order is inclusive of PC)
b.	TFT Monitor with Keyboard (Optional)	One Box	
c.	Printer (Optional)	One Box	
d.	Integral TL reader unit TL1009.	One Box	

3. Unpack these items gently & place them on a table.
4. After placing the units on the table.

Now either keep cap of the Nitrogen flushing nozzle in closed condition or connect it through a flexible pipe from Nitrogen cylindrical to allow Nitrogen gas.(optional)

5. Now make Interconnections as given in the table in CHAPTER IV, including A.C.Mains cards for PC, Printer and Integral TL Reader.

CHAPTER - I

INTRODUCTION

Thermoluminescence is a phenomena observed in certain solid-state materials like calcium sulphate, lithium floride, etc. These materials when exposed to nuclear radiation, they absorb radiation and develop defects in their valence structure. These defects are released in the form of light output on heating upto certain temperatures and normalcy is restored. The amount of light output released by these materials is proportional to the radiation dose absorbed. This is the principle of Thermoluminescence.

Nucleonix has developed a PC controlled system for the measurement of TL emission of various TL Phosphors. Materials in different forms such as powder, crystals, pellets, discs, micro-rods, etc can be studied. Thus system records digitized TL output Vs Temp profile Vs time.

Thermoluminescence Analyser Type TL1009 offered by NUCLEONIX is a versatile standalone Integral system for acquiring TL data. NUCLEONIX TL Analyser becomes an important tool for research studies in Radiation Dosimetry, Geology and Archeology. TL is a well known technique widely used in Radiation Dosimetry for routine dosimetric work in Radio diagnosis therapy and nuclear medicine departments. Apart from this our system can be used for research purposes for studying the characterstics of newly developed phosphors. The system can also be used to measure dose received by TL materials and finds applications in Environmental Radiation Dosimetry.

This system essentially has two parts :

1. Integral TL Reader.
2. Personal computer system with TL data acquisition & analysis software.

   The entire electronic hardware consisting of LV & HV supplies, temperature controller and thermocouple amplifier circuits, microcontroller based data acquisition circuit, PMT, heater transformer, kanthal strip for sample loading with drawer assembly etc are all housed into single enclosure. This unit has 20 X 2 LCD display to shownup status display of biasing voltage of PMT and temperature of kanthal strip.

   Rear panel has USB port for connecting to PC. Additionally there are test sockets for checking LV supplies & Nitrozen inlet nozzle. Windows based TL data acquisition & analysis software with GUI forms th user interface.

   Software facilities user to program for a variety of heating profiles and heating rates. Additionally a THREE point temperature calibration facility was provided for the user. Other functions provided include filing, saving of data, glow curve display visualization, ploting, printing, overlapping etc.

CHAPTER - II

SPECIFICATIONS

HARDWARE SPECIFICATIONS :

PMT HOUSING AND TL SAMPLE HEATING ASSEMBLY
This unit has a photomultiplier Tube generally of Hamamatsu / ET make, is used. However , assembly facilitates one to go in for other photomultiplier Tubes also with appropriate modification in the PMT socket wiring.

The cylindrical shell containing the Photomultiplier is fitted on to a rectangular base drawer block containing a heater arrangement and thermocouple, heater rods, connected to a power transformer .

HEATING ARRANGEMENT
Resistive heating method.

HEATING ELEMENT : (HEATER STRIP)
Kanthal strip (72% Fe, 23% Al and 2% Cr or Nichrome) is used as a heating element.
Kanthal Strip has a circular depression of 14mm to hold discs and powder samples.

HEATING PROCESS
Programmed heating can be done in two modes:
i. "PROG MODE" of Temp. controller through personal computer program.
ii. "ISO MODE" (Internal mode) of Temperature Controller , by varying the ten turn dial.

TEMPERATURE SENSOR
Thermocouple Sensor (Cr-Al spot-welded to heater strip).

HIGH VOLTAGE TO PMT : A continuously adjustable HV (0 to -1000V) @1mA is generated by HV circuits. User can select desired HV from front panel. There is HV socket (test) for checking HV presence on rear panel.

AUTO -RANGING
Current output from the photomultiplier is taken to I-F converter, to give frequency output proportional to PMT current. This wide dynamic range is achieved for plotting TL intensity on Y-axis

TEMPERATURE RANGE
From room temperature upto 500^0C, in linear, linear clamped mode of heating can be programmed.

HEATING RATES
Heater strip can be programmed to heat the sample from 0.5^0C/sec upto 40^0C/sec and a max set temperature (allowed) is 500^{0C}C.

ARRANGEMENT FOR OPTICAL FILTERS
One Heat absorbing glass / filter (IR cutoff filter) : This is essentially an IR cut-off filter which allows only visible light and cuts- off IR Radiation has been provided just below the PMT window. Additionally filters (Band pass) if required by the user may be positioned above with IR filter.

NITROGEN FLUSHING NOZZLE
Nitrogen gas flushing (sent through a flexible rubber pipe), suppreses spurious luminescence from oxidation effects & combustion phenomena has been provided.

DIMENSIONS OF INTEGRAL UNIT
25.5W X 26ht. X 48D

SOFTWARE FEATURES :

FILE HANDLING
The features include file (Glow curve data) saving, Retrieving, printing & overlapping.

CONFIGURATION
This menu facilitates the user to set comport, perform temperature calibration, set temperature profile.

DATA ACQUISITION
Data acquisition, display, plotting, download, setting sample type etc are featured under this menu.

GRAPH & PROCESSING
Setting of Y-scale factor , 3-point smoothening of glow curve, data multiplication and subtraction functions etc are configured under this menu.

REPORTS
Reports for fixed geometry samples as well as for powder samples are generated through this menu, to give dose

CHAPTER-III

SYSTEM INTERCONNECTION DETAILS

System unpacking, installing PMT & mounting all the units on a table etc., have been covered under unpacking.

Below table gives the details of interconncetions between various units and sub-systems.

S.No	Instrument/Unit	Connection from	Connection to	Type of cable
1.	TL Reader unit (from rear panel)	A.C Mains socket (230, AC)	To TL1009 on R.P MS-S0cket (3 pin)	3-pin MS-Connector wit 3 core mains cable to 3 pin A.C plug.
2.	CPU (Rear panel of CPU)	PC Rear Panel	TL Reader Rear panel	USB to USB cable
3.	CPU (Rear panel)	PC rear panel / Front panel	Printer	USB to USB cable

S.No.	Instrument / Unit	Connection from	Connection to	Type of cable	Type of signal
4.	Monitor (rear panel)		P.C Video connection	---–	Video signal to monitor from PC
5.	Monitor (rear panel)	A.C Mains 230V	Monitor (rear panel)	Mains card	A.C Power to monitor (some times it is taken from CPU unit
6.	CPU unit	A.C Mains 230V	A.C Mains socket	3 cards main card	230V A.C mains

CHAPTER - IV

HOW TO OPERATE

4.1.1. Make the system interconnections as detailed under SYSTEM INTER CONNECTIONS.

4.1.2. Keep all controls, knobs and switches to default settings
(as mentioned under Chapter VI)

4.1.3. Load TL Reader software CD by referring to the software manual.

4.1.4. Refer to TLD software user manual for details on method of configuration and TL glow curve acquisition.
Configure for a required heating profile or choose previously saved default heating profiles.
Go through four point temperatue cablibration and switch ON the heater ON switch. (with ISO/PROG switch in PROG mode).

4.1.5. Then choose 'Main Screen 'after configuration .
(Refer to TLD Software user manual for details on configuration and TL glow curve acquisition).

4.1.6. Load the TL material in disc, pellet, crystal, chips or powder form under study on to the kanthal strip after weighing accurately in case of powders and close the drawer.
a. Before making any measurements or acquiring a glow curve for a TL sample, read the instruction manual on "How to make TL measurements more accurately & correctly".

4.1.7. Start acquisition by clicking on 'ACQUIRE' (A) icon.

4.1.8. Acquisition will go on from ambient temperature to set temperature as per the selected heating profile. PC display will present digitised GLOW CURVE after acquisition indicating TL intensity Vs Time and Temperatures.

4.1.9. Acquired glow curve can be saved as file with time and temperature parameters apart from TL intensity. As per software features user can analyse, print, plot and do other function as desired.

4.1.10. Before you load another, sample, rerun & acquire for background with the same sample & save it as a BG file.

4.1.11. Brushout the powder (or takeout the disc) into bottom collection tray & reuse.

4.1.12. Open the PMT drawer slightly & allow it to cool to atleast 40^0 C before next sample can be loaded, & run.

CHAPTER - V

DEFAULT SETTINGS

After making all the connections user may set the switches and knobs to default values before proceeding with glow curve acquisition.

Default setting on the instrument :

TEMPERATURE CONTROLLER

*	ISO / PROG Toggle Switch	-	Keep the Toggle switch to 'ISO' mode initially to check the working of the reader by heating in ISO mode. Then to "PROG" mode, for normal acquisition of a glow curve.
*	SET TEMPERATURE (DIAL)	-	Not Applicable in PROG mode. Applicable only in ISO mode. How ever it can be left at minimum position. When operated in ISO mode approx every two turns correspond to 100^0c.
*	HEATER ON /OFF Switch	-	Initially OFF position, when the equipment is switch ON. Then change to ON position before ensuring that Temp in TC display should indicate room temperature or ambient temperature of kanthal strip. If temperature indication shown is near to 'zero' or -ve, then the thermocouple could be in broken condition/open condition. If found, so it should be rectified / replaced befor switching on the heater ON switch.
HV ON (0 to -1000V) :		**-**	Toggle switch initially in OFF position before switching ON the instrument.
* Once the instrument is put on then switch this enable HV to PMT.			
HV dial (0 to -1000V)		-	This can be increased to typically set the HV bias to PMT at -700V to -900V or as required.
A.C.Mains ON /OFF switch on (Rear panel)		-	Initially in OFF position. After ensuring all the F.P controls to default settings and ensuring connections between PC and TL1009I, switch ON the A.C. mains switch on Rear panel to power the instrument.

CHAPTER - VI

PRECAUTIONS / OBSERVATIONS

a. Before the power is switched ON ensure all proper connections & default control settings are made.

b. See that the 20 X 2 LCD display is working and is indicating the room temperature/ambient temperature. if LCD display indicates near zero or -ve value then thermocouple connection is open.

c. EHT adjust knob on HV module is set to minimum position (Anti clockwise). Always reduce the PMT bias HV to minimum before switching the power OFF/ON .

d. After switching ON the equipment allow ten minutes warm up time before useful measurements are taken up.

e. Ensure ‘HEATER ON' toggle switch to OFF position, each time before switching on the power to equipment.

f. Ensure ISO / PROG toggle switch to ‘ISO’ position and 'SET TEMP’ dial to minimum on before switching ON, the instrument.

g. Ensure proper thermocouple output polarity signal to temperature controller circuit whenever a new kanthal strip with thermocouple spot welded is changed. In case Kanthal strip burns off or temperature reading is not proper, then replace the damaged "Kanthal Strip with thermocouple wires" by a new one (as per the detailed procedure given in Chapter IX) and go through 4 point temperature calibration.

h. Quit the TLD software or from any of the menus in appropriate manner.

i. Each day you switch ON, before any measurements , go through four point temperature calibration after initial warmup of 5 minutes.

CHAPTER - VII

BLOCK DIAGRAM DESCRIPTION

In the introduction, principle of thermo luminescence has been explained.

This system essentially has an integral reader unit connected to PC through a serial port cable which works as a complete PC controlled TL Reader under software control.

Entire electronics comprising of LV/HV circuits temperature controller circuits, data acquisition logic which is microcontoller based with embeded code, heater transformer, I to F convertor PMT, PMT Housing, sample heater strip with drawer assembly etc, has been integrated into a single enclosure.

This PMT housing with drawer assembly has a PMT & arrangement for loading TL phosphor in any form such as powder, disc, micro-rod, pellet chip etc., which is placed on the circular depression of a kanthal strip. There is a heater transformer, which provides current to the heater strip. Heater strip has thermocouple spot-welded at the bottom of it. This thermocouple wire leads are taken to the front side of drawer (just behind front handle), and is again pushed back through a small hole along the sample drawer assembly, and gets connected to "Temperature controller PCB".

High Voltage module as indicated in the block diagram provides D.C. bias to the PMT. It can be varied from (0 to -1000V). HV indication is provided on the LCD display connected from inside of Front Panel. Typical bias being set depending on PMT used.

Thermocouple output is connected to Temperature Controller PCB. This Temperature Controller board amplifies the thermocouple output and temperature indication is provided on the LCD display connected from inside of F.P. Also parallelly the TC output is sent to Data Acquisition card . Heating is controlled by the data Acquisition Module as per the heating profile programed card.

Temperature to strip is controlled by a TRAIC-UJT circuit loop, which controls conduction angle of primary voltage to the heater transformer.

A high gain summing amplifier with one input from amplified thermocouple and other being reference signal, controls the UJT-Oscillator which inturn controls TRIAC firing.

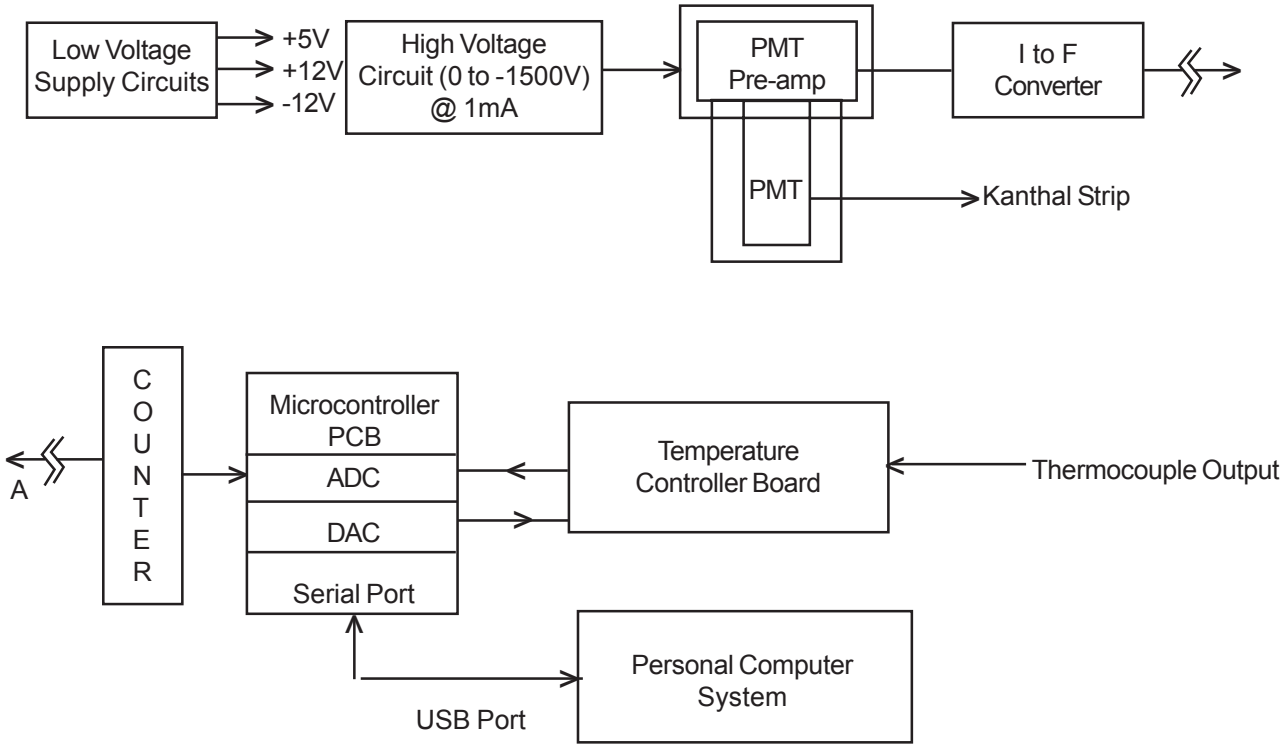
TL output received by PMT is sent to I to F convertor which converts this current to frequency signal and is fed to TL Acquisition Module. TL Acquisition Module plots TL intensity on Y-axis of the TL glow curve plotting.

TL Acquisition card reads temperature and TL intensity (I-F) and downloads these values into PC, at the end of acquisition. DAC is programmed to generate different heating profiles for heating the sample. The printer attached to PC under software control provides plot-out of glow curve & printing of TL intensity, temperature, glow curve analysis report etc.

PC software coded in VB, provides GUI and required functions for the user to interact with the system function such as acquire, file,display, print, plot, vertical scale expansion, soomthing etc., are achieved through this. Additionally four point temperature calibration, configuring for a required temperature profile etc., are achieved .

Further for the temperature profile, for DAC programming in data acquisition and controller card, PC sends the required computed data values.

BLOCK DIAGRAM OF TL1009I



CHAPTER - VIII

PROCEDURE FOR REPLACING THE DAMAGED KANTHAL STRIP

Once it is identified that either a thermocouple wire is broken, damaged or kanthal strip is burnt, then one can proceed with dismentling operation as detailed in following steps.

Take a star / flat screw driver of appropriate size and unscrew the kanthal srip, from top of the brass rods, in the drawer assembly.

Lift the front flap, below which thermocouple is soldered to long wires.

Move the sleeves on wires aside and desolder the thermocouple wires or desolder thermocouple ends if there is terminal block. Now hold the burnout Kanthal Stip and gently remove it out.

Hold new Kanthal strip with thermocouple wires facing towards you and Kanthal stip away from you and Insert gently the thermocouple wires without breaking the wires into the hole H1 till the pair of wires comeout of the hole H2. Now push the sleeves aside and solder the thermocouple wires to the PVC/teflon wires (W1) and cover the sleeves completely or if there is terminal block arrangement (recent modification), then solder onto it straightaway.

Screw up the kanthal strip.

Now keep the heater switch in OFF position and switch ON the unit and, place a hot soldering iron on kanthal strip and observe the LCD display reading.

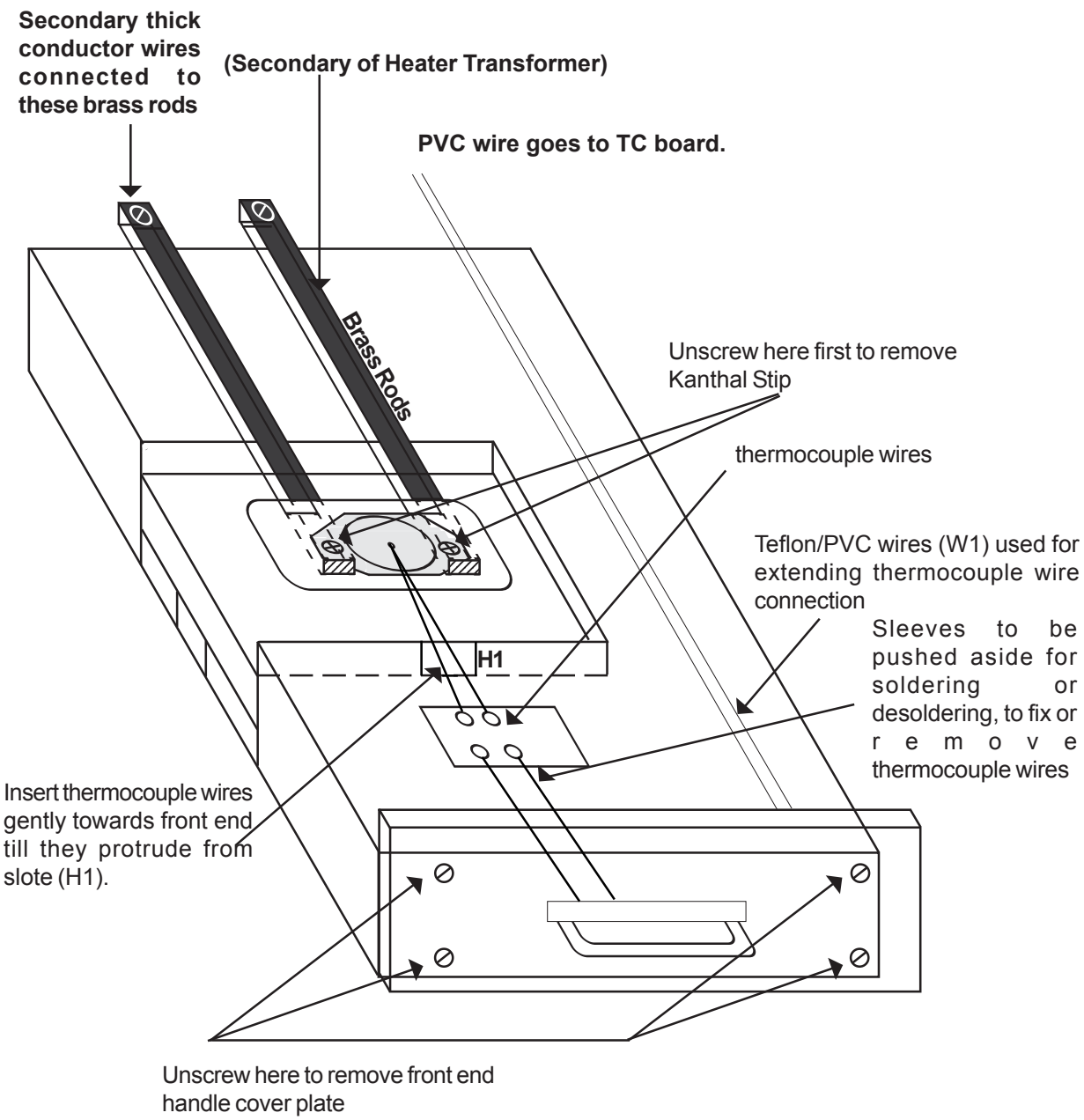
If the temperature increases with +ve sign that means you have connected the thermocouple wires with proper polarity. Otherwise desolder the connections and interchange the two wires. Now again observe to ensure +ve temperature indication on LCD display, to ensure that the fresh connection made is O.K.

Push the sleeves to cover the soldering joint (old design).

Close the flap.

After this, the heater ON switch on heater ON switch can be made ON and check heating in ISO mode by slowly increasing the dial by one turn and observe the temperature to be 50^0 C (100^0C in old design). For two turns approx 100^0C and for three turns 150^0C etc., and reduce the dial and switch OFF the unit. Now the unit is ready for use.

THERMOCOUPLE WIRE ROUTING IN PMT HOUSING


Secondary thick conductor wires connected to these brass rods
(Secondary of Heater Transformer)
PVC wire goes to TC board.
Brass Rods
Unscrew here first to remove Kanthal Stip
thermocouple wires
Teflon/PVC wires (W1) used for extending thermocouple wire connection
Sleeves to be pushed aside for soldering or desoldering, to fix or remove thermocouple wires
H1
Insert thermocouple wires gently towards front end till they protrude from slote (H1).
Unscrew here to remove front end handle cover plate

CHAPTER - IX

HOW TO MAKE TL MEASUREMENTS MORE ACCURATE USING NUCLEONIX PC BASED TL READER SYSTEM

I. Precautions to be observed for measurements and screening of dosimeters. (chips, micro-rods, discs, mini discs etc.,)

If you are working with teflon coated discs,

a. Choose a set of discs from the same batch production from your supplier.
b. Preserve them in clean conditions.
c. Do not allow dust, dirt, scratches on disc.
d. Do not handle with bare hands. Better to use forceps and place them gently onto the kanthal strip.
e. Discard buckled or wraped discs if you find them either initially or after few measurements.
f. Disc should make total contact onto the kanthal strip.
g. Each disc is to be screened before being accepted for doing meaningful measurements.
h. Expose a set of discs from the same batch for a known dose and acquire for TL glow curve for each disc atleast 3/5 times. For each disc computer the average area and deviations from the average area. The deviations shall be in close limits (limits can be decided by the user) then accept them and use for measurements. (say, the deviation is within 10% to 13% as per users choice). If any disc is found to give inconsistent/large variations, then discard such dosimeters from using for measurements permanently.
i. Of the screened discs you may find a few of them giving excellent reproducibility. Such discs could be put separately and used for calibration and evolving reader factor in a particular range. These are called calibration dosimeters. The rest of dosimeters which have fairly good reproducibility within acceptable limits (deviation within 10% or 15% as set by user) can be called as field dosimeters. (In medical dosimetry they are called patient dosimeters).

All the above points mentioned hold good for micro rods and chips also. The advantage of using these discs, mini discs, micro rods and chips is that one need not weigh them, as they are supposed to be of equal weight.

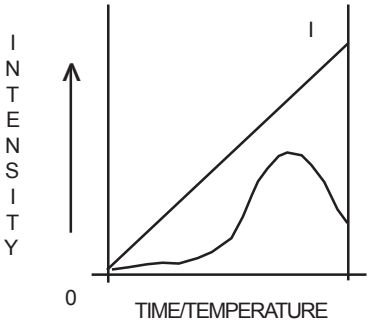
II. PRECAUTIONS TO BE OBSERVED FOR MEASUREMENTS WITH TL MATERIALS IN POWDER FORM

a. It is very important to measure the powder accurately and place it onto the kanthal strip.
b. Accuracy depends mainly on the accurate weight measurement.
c. Powder should not be placed on the kanthal strip as a heap but should be spread uniformly. This ensures that while heating takes place all the particles in the powder get heated up to the same temperature.
d. While disposing from the kanthal strip, it should be gently brushed aside, so that powder particles fall onto the collection tray.
e. Any particles left out may contribute to the next measurement as a residual TL adding to the next sample, measurement being inaccurate to that extent.

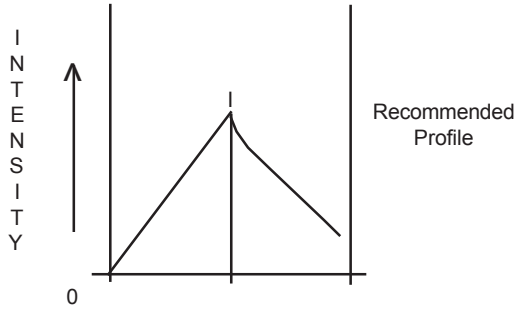
III. CHOOSING APPROPRIATE HEATING PROFILE

a. Depending on the type of TL material ($CaSo_4$, LiF or other material) and the form in which it is used (disc, rod, chip, powder crystals, pellets etc.) the heating profile is to be chosen.
b. The purpose of choosing most appropriate heating profile is primarily to maximize TL output and leave minimum residual TL in it. Also to minimize the contributions due to the thermal & IR emissions.
c. Most commonly used heating profiles are

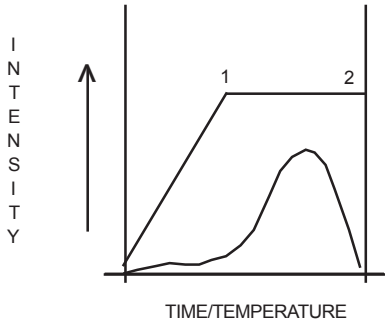
i. Linear



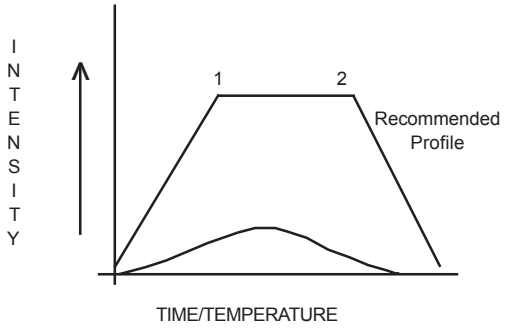
ii. Linear with cooling region included in total run time



iii. Linear clamped (Single Plateau)



iv. Linear clamped with cooling region included in run time



d. For teflon coated disc, it is desirable to choose either linear clamped or linear clamped with cooling region. Longer clamping duration may be required to ensure that TL emission is complete and residual TL is completely removed.

e. Clamping temperature around 300°C is more than enough in majority of cases for normal TL materials (other than pottery, sand and geological samples).

f. Thermal emission starts above 300°C onwards hence it is important that we restrict heating to set temperature upto a maximum of 300°C. Upto 350°C in some cases provided there is good IR cut-off filtering done.

g. For low level TL measurements nitrogen flushing is strongly advised. Infact for all measurements if it is provided it helps in any spurious signal due to oxidation and other effects.

h. For low level TL measurements it is better to choose a heating profile of "Linear clamped with cooling region included". Because some TL curve may extend into this region. Also, restrict clamping to 300°C to restrict thermal contribution.

i. The most recommended heating profiles are "C(2)" & "C(4)" for powders such as $Caso_4$ and natural discs, micro rods etc. Typical heating rate may be 5°C/sec. (i.e., Time to be selected for profile region (0-1) will be approx. 60sec) Profile region (1-2) will be "0 (zero)" sec and total run time can be selected as 75 sec (this makes the cooling region to be approx. 15 sec – enabling glow curve acquisition to be recorded in this region also.) If user wants to select other heating rate, say 10°C/sec, then select profile region time between (0-1) as 30 sec, between (1-2) as zero & run time as 45 or 50 sec. This is linear profile with cooling included, but without clamped region.

Sometimes it may be better to clamp at 300°C for certain time say 5 to 10 sec or even more to ensure that no residual TL is left. In which choose profile "C(4)". For powders clamping for 5 to 10 sec may be enough.

After first time TL acquisition, if you rerun the same sample, you will get background profile, which will also indicate if there is some residual TL.

For teflon embedded/coated discs, recommended profile is "C(4)" and it is essential to clamp it for longer duration of the order of 40 to 6 0sec. (Profile region {1-2}). Linear heating region (0-1) may be about 60 sec and total run time can be about 150 sec to include some cooling region.

Typical profiles, glowcurves & printouts obtained on this system have been enclosed for ready information and reference for user convenience.

j. The best way to acquire for background is after the TL glow curve acquisition, once again acquire for background and save this file as bdg.glo (by default). This way if it is done it will indicate whether IX has been fully extracted and what extent of residual TL is remaining in the background.

Annealing of TL phosphors (power or disc or crystals etc.) :

Proper annealing the TL phosphors in a **Hot air circulating Annealing** oven is essential, each time TL is read. Powder can be places in a SS pan & discs, micro-rods etc on a SS tray inside the oven. Temperature of the order of 280° to 300°C or slightly higher temp. may be adequate for most of the TL phosphors. Time of annealing can be suitably chosen by the experimentalist. If the annealing is not complete, then it will give rise to **Residual** TL emission. For any TL laboratory **annealing oven** is must, without which TL measurements cannot be carried out.

IV. Computing Reader Factor and Range correlation factors and other observation to be made for accurate measurements.

a. Reader Factor (RF): It is the ratio of the "Total dose" (absorbed by the dosimeter in mR, R, etc.) by the "Net TL glow curve area under the markers" (after background subtraction).
Say,

$$R.F = \frac{\text{Total Dose}}{\text{Net area of glow curve}}$$

Note: i. For computing R.F use screened dosimeters.
ii. R.F is valid for a specified EHT (HV) set. If HV is varied, the sensitivity changes, hence R.F. changes.
iii. Also this is valid for a set of same class of dosimeters of same weight or size and TL material.

b. Once R.F. is computed, the system remembers it and for all other measurements it computes and reports the dose equivalent.

V. CALIBRATION OF DOSIMETERS FOR YOUR APPLICATION & MEASUREMENT

Your application could be an kind of measurement involving, X-ras, linac, gamma radiation etc., either using machines directly or indirect measurements such as scattered radiation or through phantoms or other attenuating media. Application can be personal dosimetry, medical dosimetry, TL material characterization, environmental radiation measurement etc. For every kind of measurement to obtain the dose absorbed (equivalent) in terms of mR, R, we need to go through the calibration process.

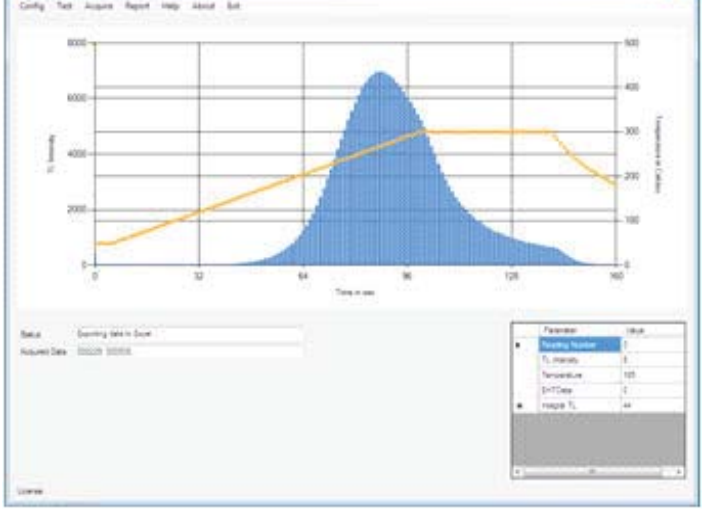
The best way is to choose a calibration dosimeters after screening and expose them under a cobalt machine for known dose. Then read it using our PC based TL Reader and acquire glow curve and obtain Reader Factor (RF), as explained.

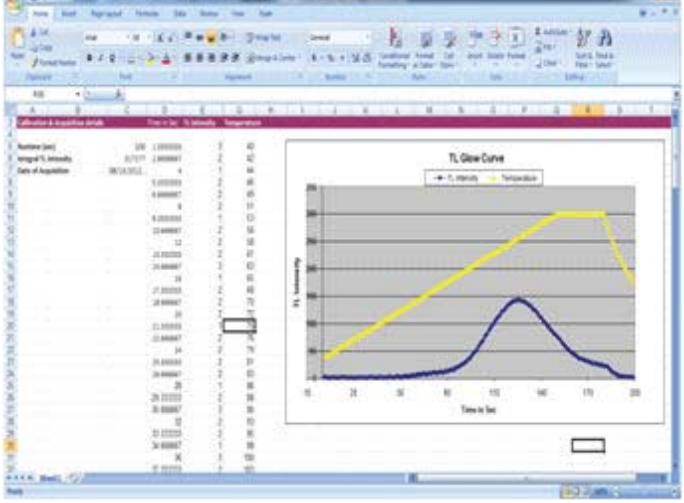
Then put the dosimeter (same) after annealing to the actual application, where the radiation, its energy and conditions may be different and make a measurement.

After acquiring the glow curve one can obtain the dose equivalent, by the following computation, which is built into the software.

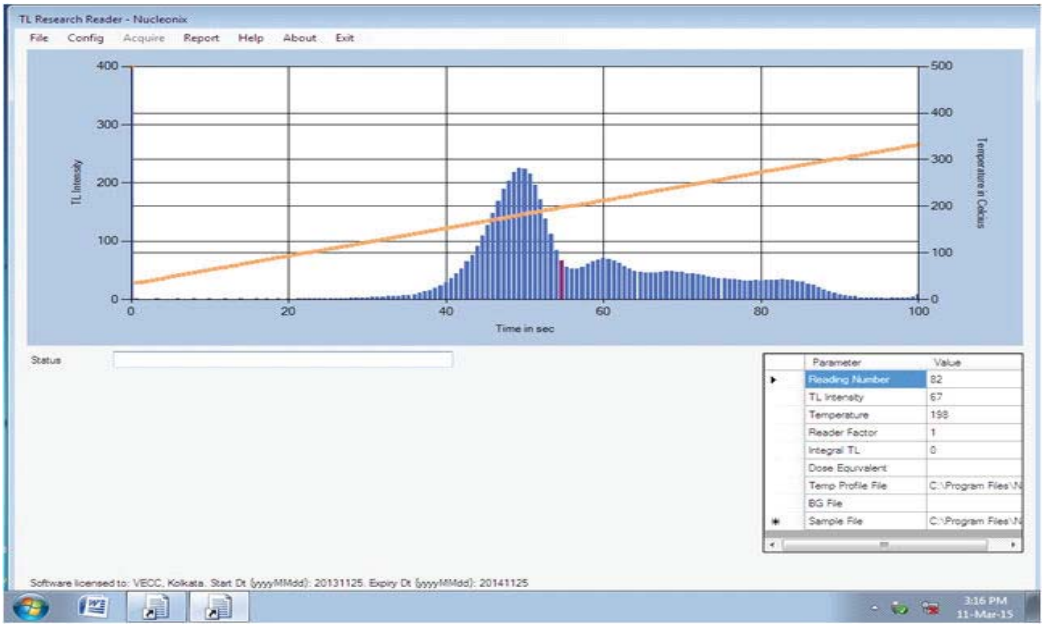
Dose Equivalent = (Area obtained) x RF
(for dosimeter under measurement)

For better accuracy it is advised to make a few iterative measurements and average the obtained results.

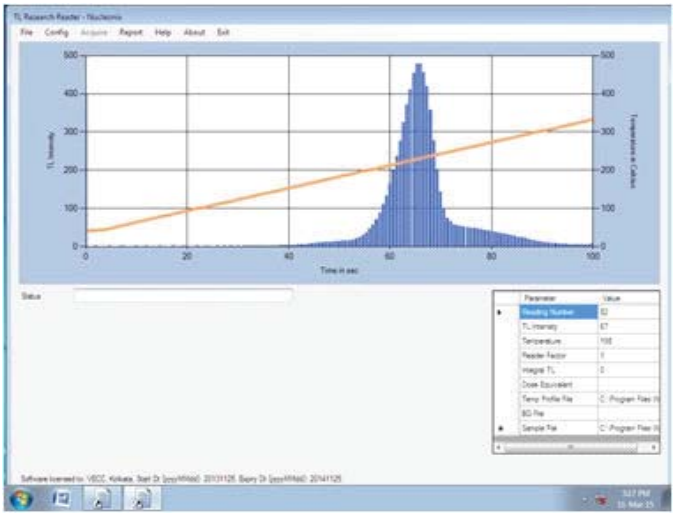




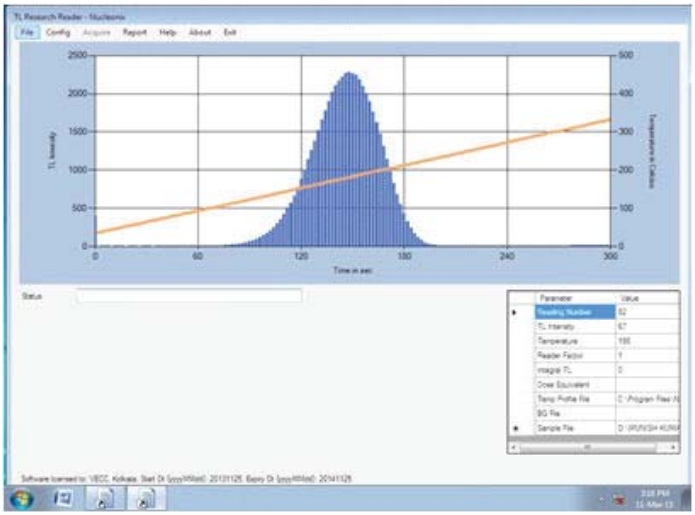
I.CaSo$_4$ Glow Curve & Its graph



II. LiF-Glow Curve [LiF-N (Mg,Ti)]



III.A) Glow Curve of LiF-Mg Copper



IV. B) Glow Curve of Al$_2$O$_3$

CHAPTER - X

1ST LEVEL OF PREVENTIVE MAINTENANCE AND ATTENDING TO SERVICE OF TL READER

Once the software is installed and working satisfactorily for everyday measurement, whenever the unit is switched ON, user can follow the following sequence.

Put all the controls in default settings.

1. Put the heater ON switch to 'OFF' position.
2. Increase the HV to –700V
3. After initial warmup time of 5min. load light source. Put the ISO/ Program switch at program position and set temperature to 0^0c.
4. Through acquisition button run for acquisition cycle. Note the counts for the channel.
5. Repeat this every day if you make measurements. It should give same measurements.
6. In acquisition you can see a band with constant light source counts.
7. Without light source, run for a profile without any sample, the background should be very low.
8. The movement you switch on you look at the temperature display. It should show close to ambient temperature, as sensed at the thermocouple. If by chance thermocouple connection broken, the display show very near to zero or small negative display. Then check for the thermocouple breakage or any other connector breakage upto the TC board. If kanthal strip is burnt or TC may be broken same will be replaced.

In case instrument not display anything check Rear panel low voltage supplies and report the problem accordingly.

If with light source you don't get any reading check for HV on the Rear panel by keeping the HV to less than 500V and selecting DC 1000V range in the multimeter.

Each day before you start the experiment, you go through the temperature calibration after warmup time.

When you are using light source you should keep the heater ON / OFF switch to 'OFF' position

RECOMENDED HEATING PROFILES

A. POWDER SAMPLE

For power samples s& also for Natural crystals/micro-rods/discs etc., low heating rate is recommended. The Normal profile to get accurate output is

Heating Rate = Typical (2^0 c/sec)
(range permitted is 0.5^0 c/sec to 40^0 c/sec

Set Temp	=	300^0c (typical)
Rise Time	=	60sec
Clamp Time	=	20sec
Run Time	=	80sec

B. DISCS (Fixed wt) with teflon base material

For fixed samples say caso4 - Dy discs, 2^0 c/sec to 5^0 c/sec is recommended

Heating Rate = 10^0c/sec (typical) = 5^0 c/sec

Set Temp	=	300^oc
Rise Time	=	60sec
Clamp Time	=	30sec
Run Time	=	120sec

CHAPTER - XI

EQUIPMENT MAINTENANCE SERVICES AND WARRANTY CLAUSE

11.1 GENERAL

As per the warranty clause of the company we provide one year warranty during which period we provide free service at our works. Hence in case of any mal-function in our instruments you are requested to send the unit back to our works by RPP/COURIER/SPEED POST PARCEL/GATI/XPS/door delivery. We shall arrange immediate rectification/replacement within two weeks from the date of receipt of the equipment at our place. Please note that the equipment will be serviced at our works only.

The equipment is to be sent to :

The Servicing Department
NUCLEONIX SYSTEMS PRIVATE LIMITED
Plot No : 162 A & B, PHASE II, I.D.A.Cherlapally,
Hyderabad - 500 051Ph : 040-27263701/329145448/32918055
e-mail : info@nucleonix.com www.nucleonix.com

For all the Radiation monitoring equipment, detectors built-in or external probes will not have one-year warranty, only inspection warranty at the time of supply is provided. Since detectors will / may have fragile glass construction we do not provide warranty. In case of failure of these components at cost price as per Nucleonix price list user has to buy.

Note : In respect of all types of portable radiation monitors, it may be necessary to checkup and recalibrate the equipment once a year at our works.

11.2 EQUIPMENT REPAIRS / SERVICING POLICY (WITH IN INDIA)

11.2.1 DURING WARRANTY

The following procedure is to be followed by the customers with in India for availing services/ repairing facility during warrantee period.

- Equipments are to be sent to our works for availing free repair services during warrantee, after the customer receives approval from the customer support division, by sending an e-mail.
- For all equipments, costing less than 6.0 lakhs one year warrantee & free service is offered, when the equipments are sent to our works only. For larger systems such as installed systems, networked systems, specialized systems, costing more than 6.0 lakhs during one year warrantee, free service is offered at site. Field service Engineer will be deputed subject to warrantee terms & conditions.
- This does not include personal computer related problems, for which local computer service provider of the PC vendor is to be contacted. Also for software related problems online support will be provided. Software support doesn't include cleaning of virus problems etc.
- When the equipments are sent to our works for warrantee services, they are to be properly packed with adequate cushion to prevent any transportation damages. Nucleonix Systems is not responsible for damages or loss during transportation.
- Packing / Freight charge is to be borne by customer when he sends the equipment to our works. However when we return after servicing packing will be Nucleonix responsibility & Freight charges will be to your account. Only services are free.
- Please indicate in your correspondence equipment model & serial number.
- All the equipments are to be sent to our works only on door delivery basis.
- For Door Delivery Transportation contact XPS/GATI cargo in your city / town or a reliable courier service to pick the consignment from your place. For their nearest local address & phone no's look into their websites. Transit insurance if the customer feels is necessary it is to be covered.
- Nucleonix Systems will not receive the equipments sent by other modes of transportation, such as Rail/Road.

- After servicing, equipments will be sent back by same mode of transport such as XPS/GATI/COURIER/ RPP.
- All types of Radiation detectors, glass ware, PMTs etc which are fragile are not covered in warrantee, if the failure is due to physical damage, external or internal due to shock, dropping, miss-handling etc. If the failure is due to a natural fault then only it is covered under warrantee for a limited period of three months. However complete electronics is covered for 1 year warrantee.
- You can also send the equipment personally to our works for repairs either during or after warrantee, after fixing up with our service dept (Customer Support Division). If possible we may repair on same day or your person can stay for a day or two & get it repaired & or calibrated.

11.2.2 AFTER WARRANTY SERVICES

- On expiry of 1yr warrantee if you like to send the equipment (low cost less than 6.0 lakhs) for repairs to our works, you may please observe the following procedure.
- Send an e-mail with details mentioning that you agree to pay service charges which includes: Basic service charges per unit / module in the range of Rs: 2500 to Rs : 10,000 depending on the sophistication of the unit calibration charges (if applicable for your equipment) + cost of components + packing charges + Return Freight charges @ actual.
- Once our customer support department responds & requests you to despatch the equipment to our works for repairs, youx may do so by following the steps given below.
- Followed by this you can send the equipment straight away if it is within 5 yrs old. If the equipment is beyond 5 yrs old, then also you can send it for repairs, however only after you receive confirmation from Customer Support Division, that it is repairable & is not an obsolete model. If the design is obsolete then customer support division (CSD) may give you 'buy back' offer to replace with new model or upgrade it with electronic circuit boards & enclosure.
- For all installed equipments costing above Rs: 6.0 lakhs which are larger in size & for which field servicing only is recommended, you can obtain a quotation with relevant details by sending an e-mail & avail the services accordingly.
- For all field servicing jobs, since we need to depute engineers, it is likely, to take time & also it will cost more which includes Engineer's TA & DA etc., apart from basic service charges + cost of spares etc. Please note that basic service charges will be different for different products depending upon sophistication.
- Also in some cases it may not be possible to fix-up the problems in the field itself, in such cases we may advise you to send them to our works.
- For all jobs to be serviced in the field, customer is requested to provide adequate details on the nature of problems, to enable our engineer to come prepared with adequate spares.
- For any additional information send an e-mail to info@nucleonix.com, Atten: Customer support division.

11.3 EQUIPMENT REPAIRS / SERVICING POLICY (FOR EXPORTS)

Equipments, manufactured & exported are subjected to a well defined quality assurance (QA) plan & Factory acceptance tests (FAT). Nucleonix systems has the following policy to provide maintenance support to overseas customers either directly or through international dealers / distributors.

(a) During & after warranty:

- For minor problems, which can be handled by customers, servicing tips have been provided in the user manual / servicing manual.
- Also most of the equipments have built-in fault diagnostic features which will indicate to the user nature of problem in the equipment. Based on the visual indication in the instrument Display, user can take corrective action or contact Nucleonix systems by email for help.
- Nucleonix systems will guide in localizing the defective part / module or sub-system by interacting with the customer if required. Skype will be used for communication.
- During warranty free replacement of sub-system or board (PCB) will be done. However customer has to send defective sub-system back to Nucleonix system with-in 15 days on arranging replacement.
- During & after warranty, any Freight charges & customs clearance charges are to be borne by customers, both ways.
- If it is a manufacturing defect, then Nucleonix system will bear the replacement cost of sub-system / unit. However any Freight charges & customs clearance charges in their country are to be borne by customer.
- After warranty, services will be similar to that of services during warranty. However, customer will have to pay for cost of parts replaced, freight charges both ways & customs clearance charges in both the countries. Nucleonix systems plans to introduce audio visuals on web or on CDs to facilitate product demonstration, installation & minor maintenance very soon.

11.4 HOW TO AVAIL CALIBRATION SERVICES (FOR INDIAN CUSTOMERS)

Nucleonix Systems offers radiation calibration services to its customers. Calibration services are provided for Nucleonix Systems manufactured products only, in general, as a company policy.

How to avail calibration services:
It is best advised that each of the Radiation monitors including Area monitors are calibrated once in a year. When you want to send your Radiation monitor / Area monitor / Contamination monitor for calibration to our works. You may send the equipment for calibration, by following the steps given below:

1. Our standard calibration charges per equipment (All types of Radiation monitors including portable survey meters, contamination monitors & Area Gamma Monitors) are Rs: 2500 + Packing + Freight charges. You can email a 'work order' accepting these charges.
2. Email your work order and despatch / send the equipment to our works if it is 5 years old or less including details of mode of transport sent with docket particulars.
3. Also mention in your work order & clearly indicate that you will agree to pay calibration charges & also equipment repair charges additionally if the unit is faulty & requires repairs before one can take it up for calibration.
4. You are requested to ensure good packing to avoid any transportation damages. Especially if there are external detector probes, they are to be packed with sufficient soft foam to ensure no damage in transportation.
5. Use only the specified following mode of transportation system for dispatching on door delivery basis. XPS/GATI cargo / Courier/RPP/Speed Post parcel etc. Send the equipment on freight paid basis. (Equipments sent by other methods such as Rail/Road etc will not be collected). Also you can cover for transit insurance both ways if you wish. Nucleonix system is not responsible for any transportation damages or loss during transportation both ways.
6. Immediately on receipt of the equipment, we will send an acknowledgement & also a proforma bill by email/ post.
7. Based on the proforma bill, once we receive the payment, equipment will be dispatched back by similar mode of transportation as mentioned above.

11.5 HOW TO AVAIL CALIBRATION SERVICES (FOR FOREIGN CUSTOMERS)

Foreign customers can calibrate Nucleonix make Radiation monitors/equipments in their country at any of their accredited Radiation calibration labs. Nucleonix systems will be happy to provide any help and guidance if needed, for calibration. Alternatively if you send the equipment here to India we can also provide calibration services.

CALIBRATION STANDARDS LAB & FACILITY :

We have two calibration labs . (1) Low level Calibration Lab (2) High Dose Rate Calibration Lab

(1) Low level Calibration Lab : This has a Cs-137, 165 mCi standard. "Gamma Survey Instruments Calibration" from Amersham.
This has NIST Traceability Calibration of all portable radiation monitors, survey meters, contamination monitors, Area monitors etc., is carried out in this lab upto 1R/hr max doserates.

Gamma Survey Instruments calibration has Cs-137 source 161.5 mCi as on 5th Aug 2002. It is basically a Gamma Survey Instruments calibrator procured from AEA Technologies UK/USA. Has NIST traceability within +/- 7%.

(2) **High Dose Rate Calibration Lab :** This lab has a 8Ci, Co-60 standard housed in a CRC-2 camera, operated remotely viewed through CCTV arrangement. High dose rate survey meters, High level Area monitors etc are calibrated in this lab. This CRC-2 camera is housed in a separate concrete building. All the radiation monitors manufactured by Nucleonix Systems are authentically calibrated at this facility, before they are shipped / dispatched.

CRC-2 camera has Co-60 standard obtained from Bhabha Atomic Research Centre, Mumbai. It is a certified source

11.6 ANNUAL MAINTENANCE CONTRACT (AMC)

Annual maintenance contract (AMC) services:
For all sophisticated instruments & systems and also for installed monitors & networked systems in a nuclear facility or a Radiological lab or in a Medical cyclotron facility where no. of instruments are networked, it is advised that customer enters into an economical Annual maintenance contract with Nucleonix system.

Detailed AMC proposal can be obtained from our customer support division (CSD), by giving required inputs.

Inputs required by our CSD to send you AMC proposal:

- Name, year & data of purchase, Sl. Nos. of equipments, Model No's, No. of equipments for which AMC is required. Additionally no. of calls per annum required for preventive & breakdown maintenance may also be indicated.

Advantage of entering into AMC:

- Equipment services offered will be prompt & timely
- Nucleonix systems maintain required spares, spare tested PCBs, detectors & other critical components which may become obsolete.
- Obsolescence in electrons is quite rapid. If you enter into AMC guaranteed service for the period of AMC will be the responsibility of Nucleonix Systems.
- Nucleonix Systems will maintain Engineers at your disposal to attend to AMC calls on time
- Without AMC prompt service calls are not guaranteed.
- If some critical components become obsolete, then Nucleonix systems may request you to upgrade the product with new model or new electronics which may be expensive if you are not under AMC.

Training on maintenance / servicing:

- To a limited extent, we offer training on maintenance / repairs at our works to customers on chargeable basis. Details can be obtained from our customer support division, by customers who may require such services.

CHAPTER – XII
CUSTOMER SUPPORT DIVISION

For sales and services :

a) For any Commercial, Price information, Product information, customer coordination & quotation of our products including servicing & calibration charges and also customer related commercial services, please contact Front Office through the above Email Ids or Phone Nos.

Whom To Contact:

Customer Support Engineers / Executives
Tel: 91-40-27263701, 32918055, 32914548.
[Mobile. +91-9393504552], Fax : 040-27262146
Email : info@nucleonix.com

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b) For **Servicing / Calibration** and **installation charges, quotation,** to know the Dispatch / Delivery schedules and for deputation of engineers and also customer related commercial services, please contact General Manager or Customer Support Executives.

Contact Official / Department:	Contact Numbers	Contact by E-mail ID
Customer Support Engineers	Above Landlines or Mobile	info@nucleonix.com
Dispatch Stores	Above Landlines or Mobile	
Office Secretary	Above Landlines or Mobile	

2.System Software Manual 33-44

Software User Manual – TL Research Reader - Nucleonix
Version: Jul 2012

SYSTEM REQUIREMENTS:

PC (Minimum configuration): Intel i3 CPU or better, 2 GB RAM, 160 GB HDD.
OS: Windows 7. (Windows Vista / XP is not supported)
Antivirus: Norton / Quickheal / Kaspersky
Internet connectivity & Teamviewer/Skype software: For remote trouble-shooting
COM port / USB-Serial convertor: For connecting Electronic Unit to PC.

INSTALLATION:

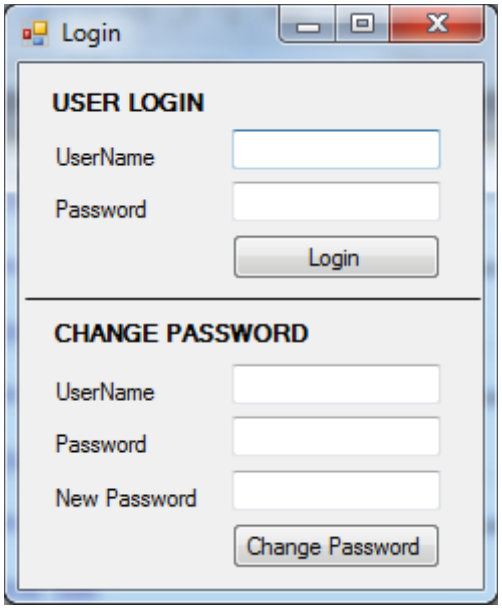
To install the software, execute TLResearchReader.bat in the installation CD. Click through the options, until you get the message that installation is completed successfully.
In case of any errors, please take a screenshot of the error message and email to Nucleonix Customer Support.

MAKING CONNECTIONS AND IDENTIFYING COM PORT:

Prepare the Reader as per Hardware user manual. Connect the Serial cable from TL Research Reader Electronic Unit to PC COM port. In case PC does not have a COM port, connect it to USB-Serial convertor. USB-Serial convertor acts as an equivalent of COM port. The drivers for USB-Serial convertor must be installed before it can be used.
After making connections, the COM port number must be identified. For this, Right click on 'My computer' icon on Desktop. Select Properties -> Device Manager -> Ports. You will find the COM port number. For eg. If you find 'COM3', it means that COM port number is 3.
Turn ON Heater switch on Reader and EHT to PMT.

EXECUTING THE APPLICATION:

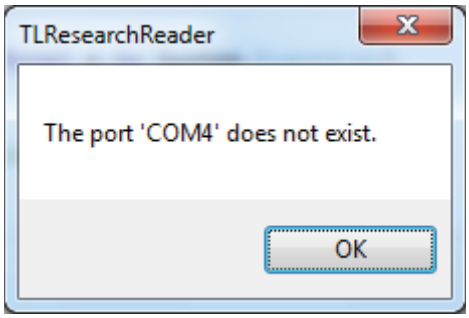
Click on Start -> Programs –> Nucleonix Systems -> TLResearchReader or Double click TLResearchReader icon on Desktop to run the application. A login window appears as below.

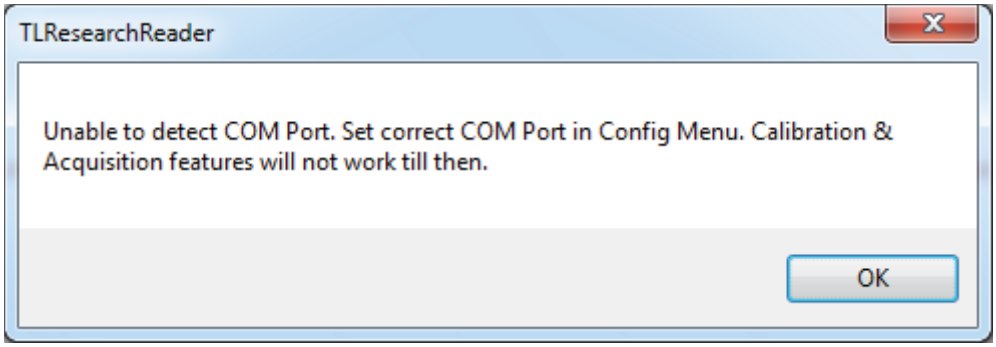


Enter "admin" as Username, "Nucleonix" as password and click on Login button. This password can be changed to User's choice, using the controls on lower part of the screen.

SOFTWARE OPERATION AND FEATURES:

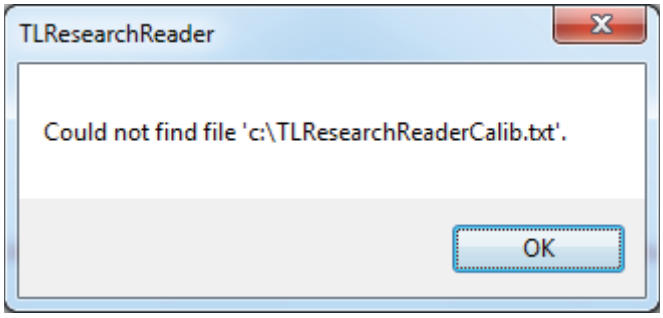
If COM port settings are incorrect, then following windows appear.

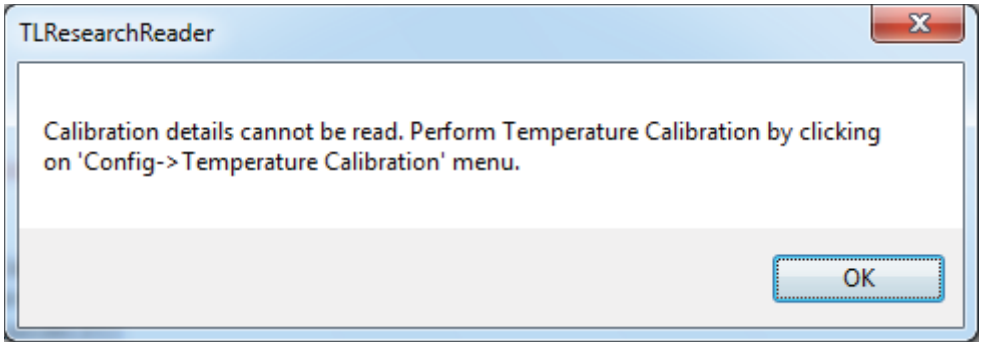



TLResearchReader
Unable to detect COM Port. Set correct COM Port in Config Menu. Calibration & Acquisition features will not work till then.
OK

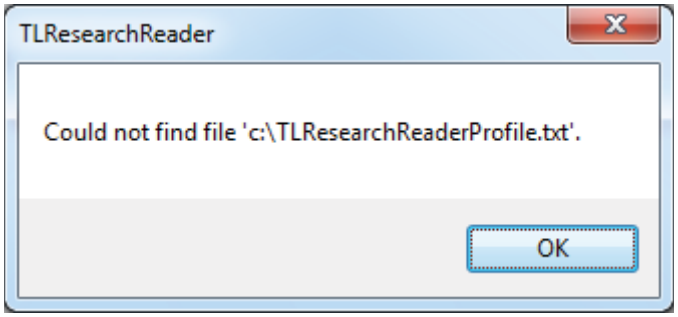
Recheck the COM port number and enter the correct COM port number in 'Config-> Set COM Port' menu.

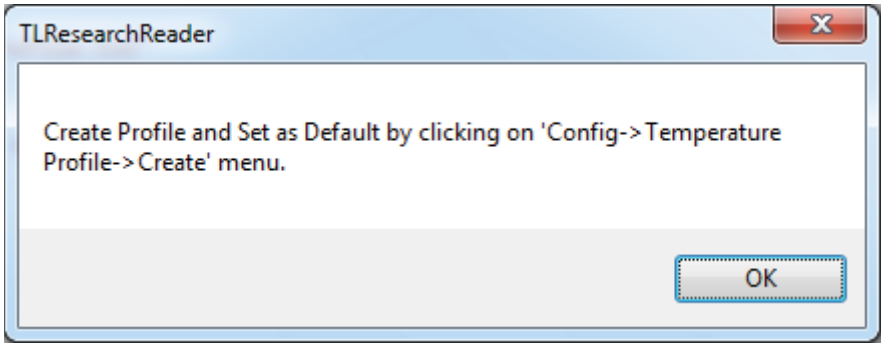
The very first time the application is executed, the below message appears.




TLResearchReader
Calibration details cannot be read. Perform Temperature Calibration by clicking on 'Config->Temperature Calibration' menu.
OK

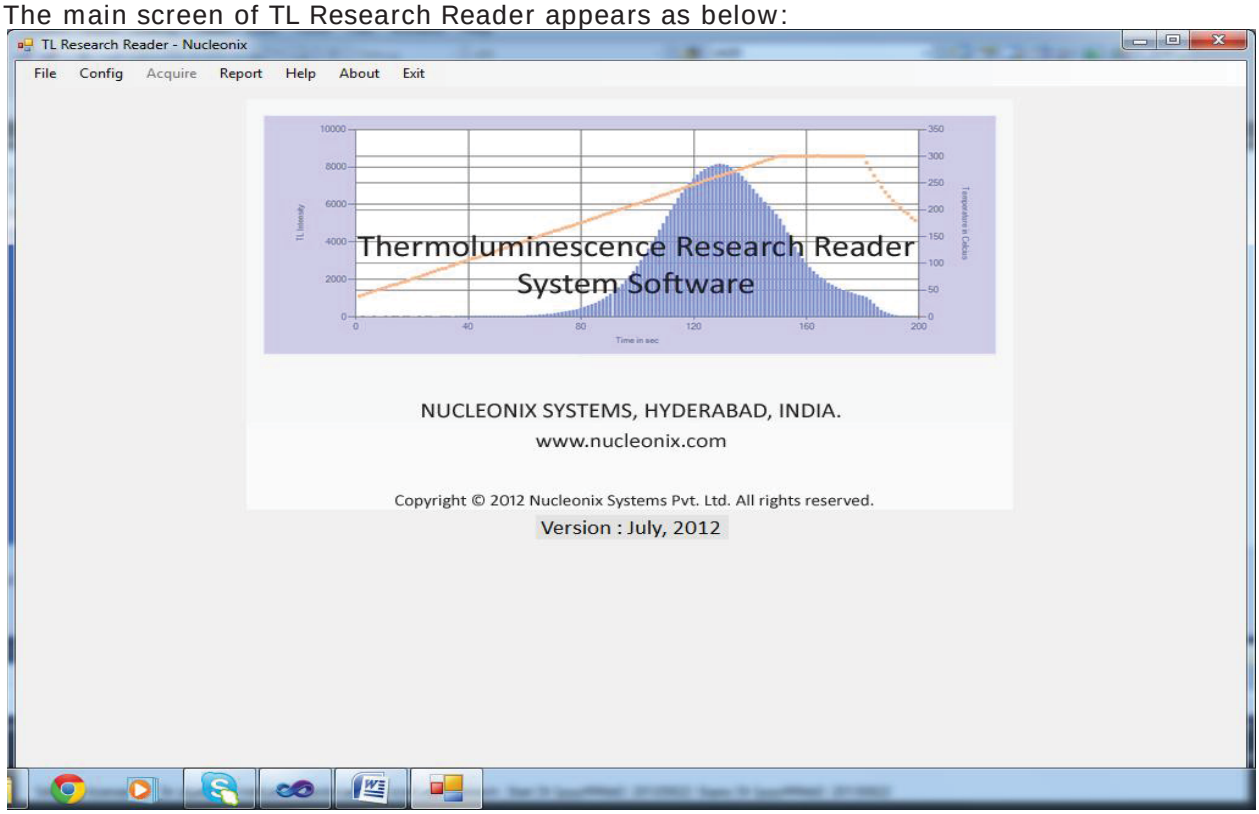
This means that no previous Temperature Calibration file exists and hence Temperature Calibration is to be performed.





This means that no previous Temperature Profile file exists and hence Temperature Profile is to be created. Click on ‘Ok’.

The main screen of TL Research Reader appears as below:



Config Menu

Setting the COM Port

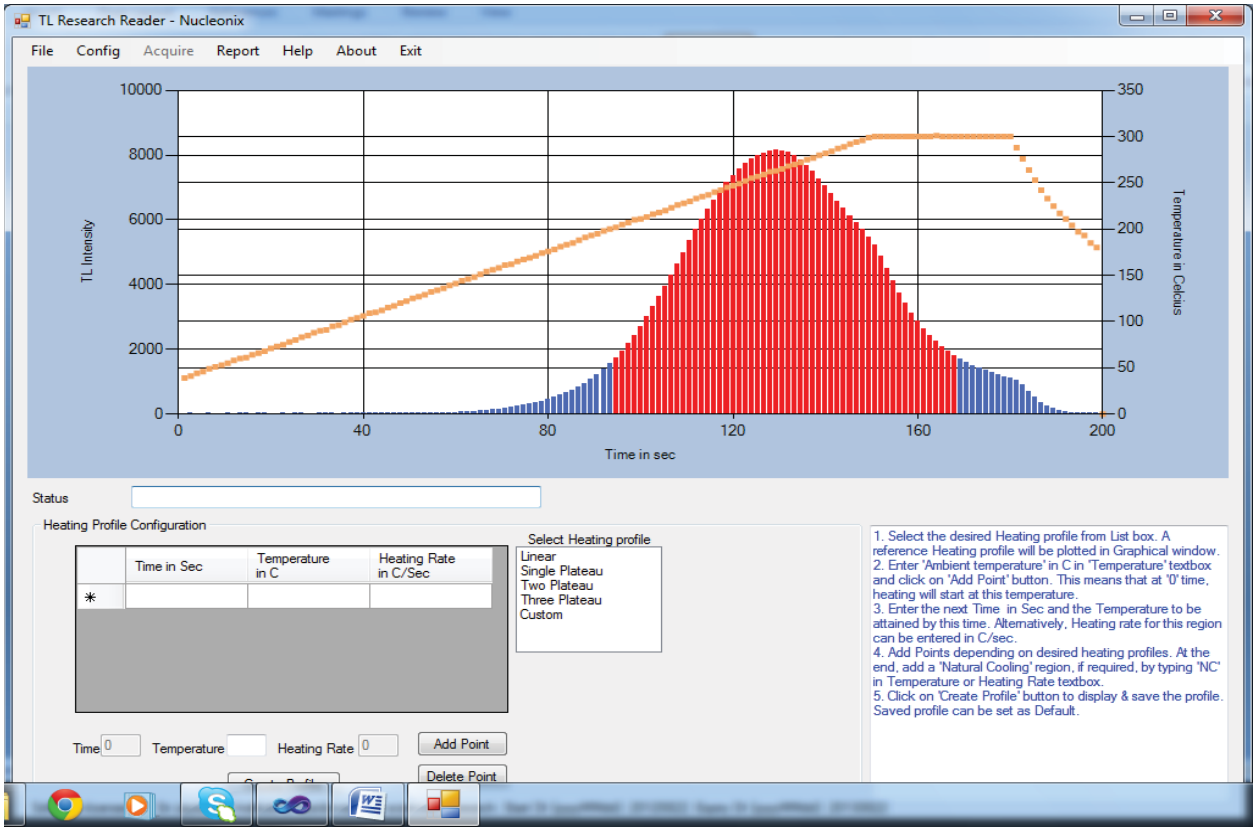
To set COM port, select Config menu and click on ‘Set COM port’. In the window that pops up, enter the COM port number and click Ok. The application is terminated for the new settings to take effect. Now ReRun the application.

Temperature Calibration

a. Temperature Calibration must be done for the very first time the Software is executed. Also, it is to be done periodically or whenever you observe deviation between Set temperature and that observed on TL Reader's display. To do this, select Config menu and click on Temperature Calibration.
b. Click on Start button to start incrementing Temperature. Observe the temperature on TL Reader’s display.
c. Click on 'Pause' button when Temperature on Reader reaches approx 150 C & enter that value in Temperature Textbox.
d. Click on 'Add to Grid' button to accept the value for Calibration purpose.
e. Click 'Resume' button to increase temperature again. Repeat steps (c) & (d) for 250 C and 350 C.
f. Click on 'Save Calib & Exit' button to Save the Calibration details. They are Auto loaded every time the App is run.

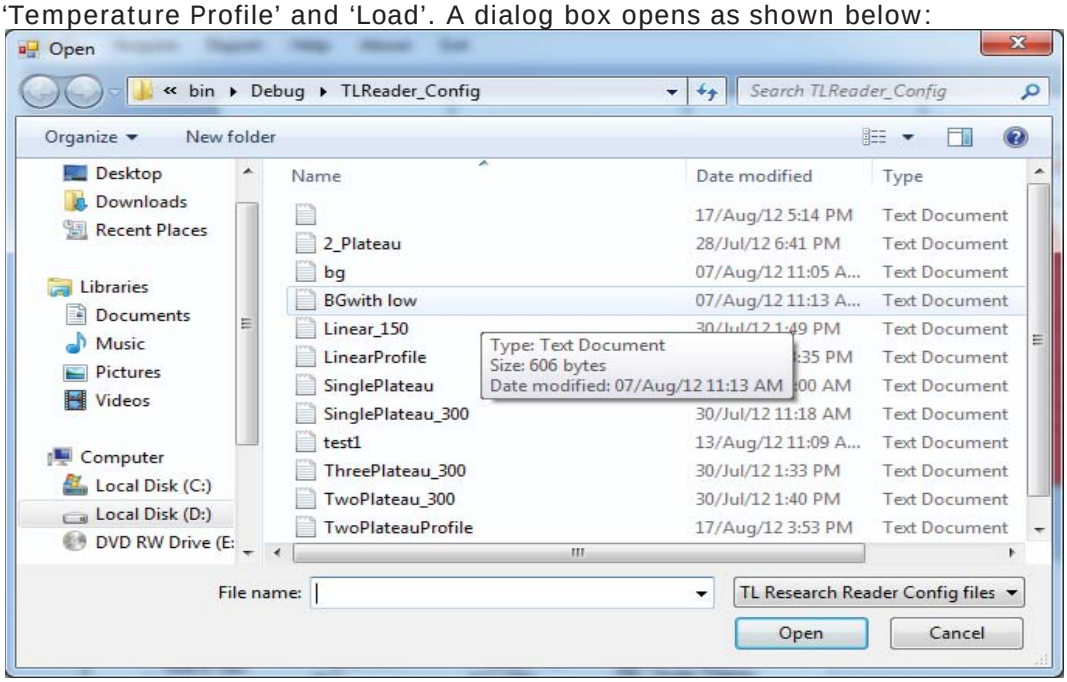
Configuring the Heating Profile

User can **Create** a new Heating Profile of the following types: Linear, Single Plateau, Two Plateau, Three Plateau and Custom and Save the Profile for re-use.
This can be done by clicking on Config Menu, ‘Temperature Profile’ and ‘Create’. The screen looks like below:


TL Research Reader - Nucleonix
File
Config
Acquire
Report
Help
About
Exit
TL Intensity
Temperature in Celcius
Time in sec
Status
Heating Profile Configuration
Time in Sec
Temperature in C
Heating Rate in C/Sec
Select Heating profile
Linear
Single Plateau
Two Plateau
Three Plateau
Custom
Time
Temperature
Heating Rate
Add Point
Delete Point
1. Select the desired Heating profile from List box. A reference Heating profile will be plotted in Graphical window.
2. Enter 'Ambient temperature' in C in 'Temperature' textbox and click on 'Add Point' button. This means that at '0' time, heating will start at this temperature.
3. Enter the next Time in Sec and the Temperature to be attained by this time. Alternatively, Heating rate for this region can be entered in C/sec.
4. Add Points depending on desired heating profiles. At the end, add a 'Natural Cooling' region, if required, by typing 'NC' in Temperature or Heating Rate textbox.
5. Click on 'Create Profile' button to display & save the profile. Saved profile can be set as Default.

The below steps can be followed to configure:
a. Select the desired Heating profile from List box. A reference Heating profile will be plotted in Graphical window.
b. Enter 'Ambient temperature' in C in 'Temperature' textbox and click on 'Add Point' button. This means that at '0' time, heating will start at this temperature.
c. Enter the next Time in Sec and the Temperature (maximum is 500C) to be attained by this time. Alternatively, Heating rate for this region can be entered in C/sec (maximum is 40C/sec).
d. Add Points depending on desired heating profiles. At the end, add a 'Natural Cooling' region, if required, by typing 'NC' in Temperature or Heating Rate textbox.
e. Click on 'Create Profile' button to display & save the profile. User must give an appropriate name to the Profile for easy identification. For eg, a Linear heating profile with 300 sec runtime can be given the name ‘LinearProfile_300’. Saved profile can be set as Default, so that every time the application is executed, the default profile is automatically loaded and this profile will be used for Acquisition.

To **Load** a specific Heating Profile other than the default one, click on Config Menu, ‘Temperature Profile’ and ‘Load’. A dialog box opens as shown below:



It shows the filenames of Heating profiles. Select the desired one and click open. A message appears to confirm that Heating profile is loaded.

Now, we are ready to acquire the TL spectrum.

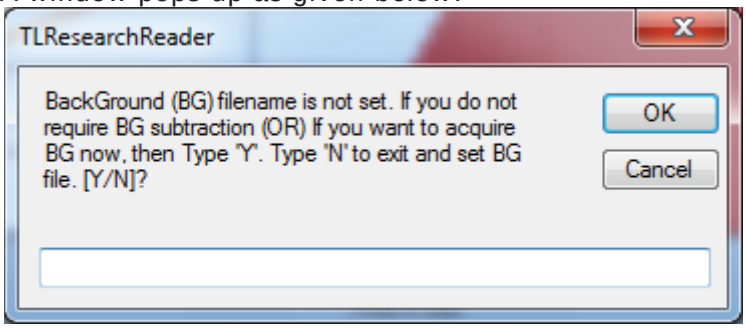
Setting Reader Factor to obtain ‘Dose Equivalent’
Setting Reader Factor enables us to get the Dose Equivalent in ‘Integral TL’ computation.

Acquire Menu

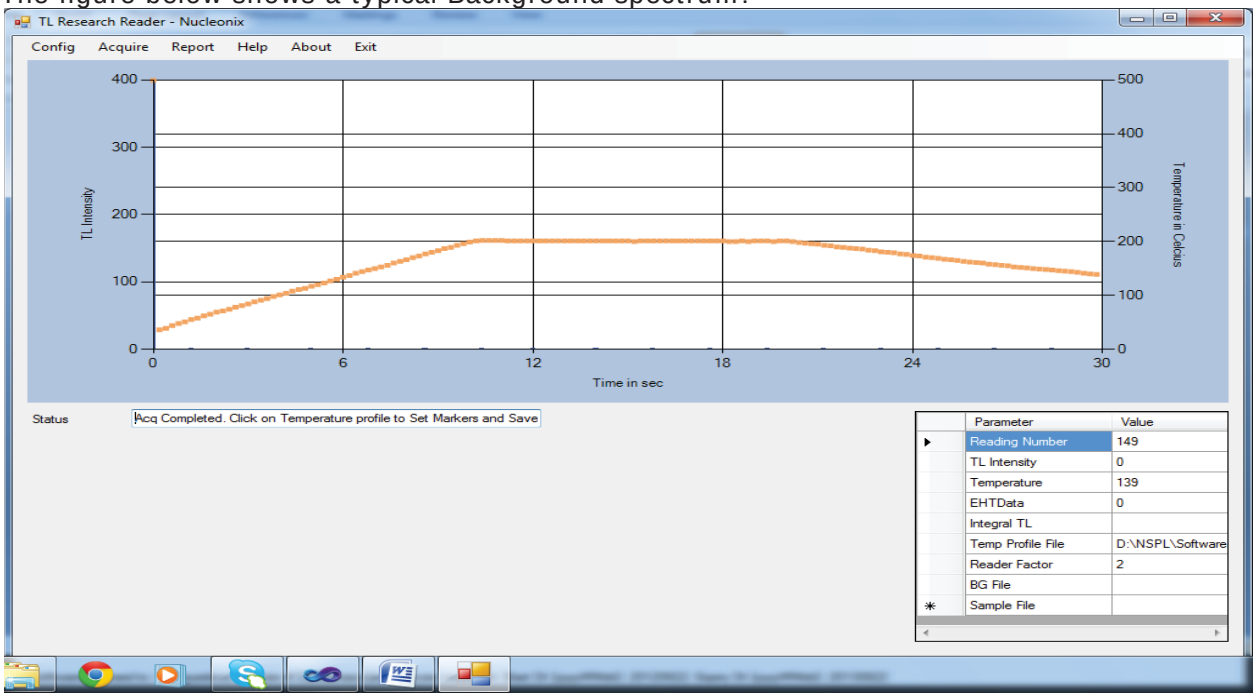
After Temperature Calibration (if executing for the first time) and creating / loading desired Heating Profile, we are ready to acquire the spectrum. Ensure that Heater switch is ON and EHT is at desired value.

Acquiring Background Spectrum

A background spectrum must be acquired before loading the sample. This can be done by clicking on ‘Acquire Menu’ and ‘Start’.
A window pops up as given below:


TLResearchReader
BackGround (BG) filename is not set. If you do not require BG subtraction (OR) If you want to acquire BG now, then Type 'Y'. Type 'N' to exit and set BG file. [Y/N]?
OK
Cancel

Select ‘Y’ as we are acquiring the Background spectrum.
The figure below shows a typical Background spectrum:



Save this file by clicking on ‘Acquire Menu’ and ‘Save’. A Window pops up in which the User must enter a filename. Enter an appropriate name like ‘BG_Aug182012’.

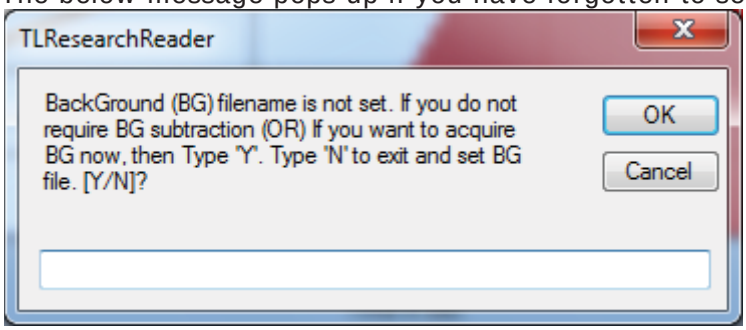
Setting BG Filename for Auto subtraction

Before acquiring Sample spectrum, we must set the Background filename to the most recently acquired background spectrum filename.
This is done by clicking on ‘Acquire Menu’ and ‘Select BG File’.

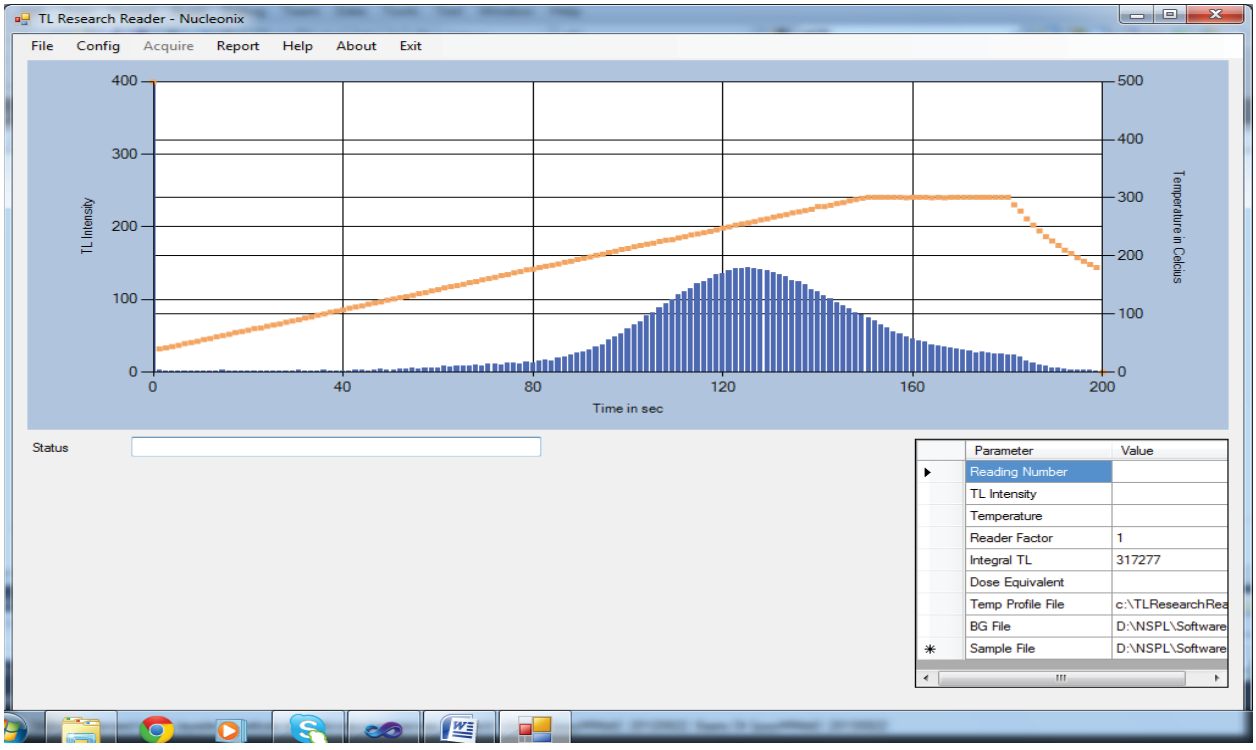
Once this is done, background data will automatically be subtracted from all the acquired samples.
If Background data is not required to be subtracted from sample data, then this step is to be skipped.

Acquiring Sample data

Load the sample in the sample holder and close the drawer tightly. To acquire spectrum for a Sample, click ‘Acquire Menu’ and ‘Start’.
The below message pops up if you have forgotten to set the BG filename.


TLResearchReader
BackGround (BG) filename is not set. If you do not require BG subtraction (OR) If you want to acquire BG now, then Type 'Y'. Type 'N' to exit and set BG file. [Y/N]?
OK
Cancel

If you choose to acquire sample data without BG subtraction, type ‘Y’. Otherwise type ‘N’ to set BG filename and return later.
Live acquisition and plotting of TL glow curve and Temperature profile starts as per the selected Heating profile. A typical profile after acquisition would look like below:



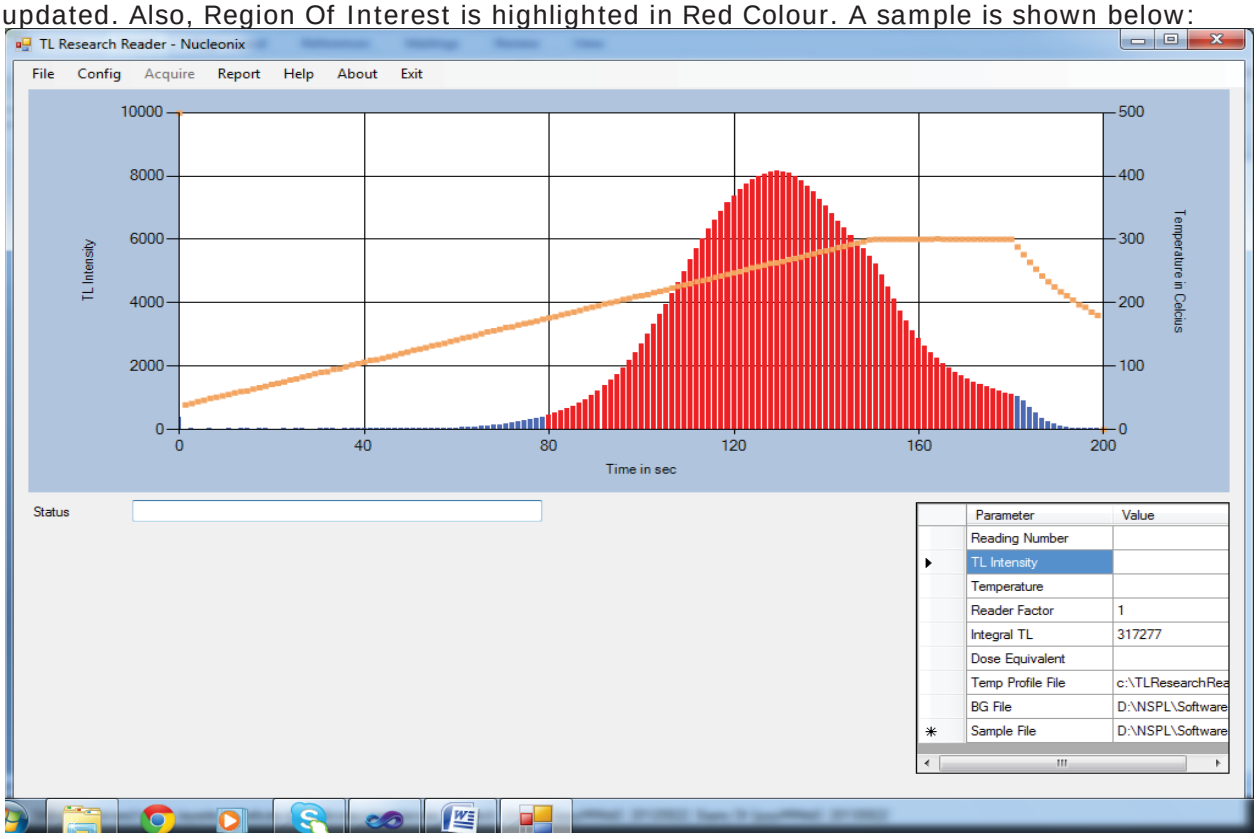
Notice the grid on bottom right. During acquisition, Reading Number, TL Intensity and Temperature are updated for every data point that is acquired.

Setting the Region of Interest (ROI) and calculation of Dose Equivalent
User can now click on the spectrum to set the Region of Interest (ROI). ROI's colour changes to Red. Integral TL Intensity is calculated for the selected ROI and displayed in the Grid. Dose Equivalent (in mR or R) is calculated by multiplying Integral TL Intensity and Reader Factor. Also find that Temperature Profile file name, BG File name and Sample file name is listed in the grid.

Saving the acquired spectrum
To save the acquired spectrum, click on File Menu and Save. User is asked to enter the filename without path and Extension. The spectrum data is saved in a text file and also exported to Excel. These files are located in c:\Program Files\Nucleonix Systems\TLResearchReader\TLReader_Spectra and TLReader_Reports folders respectively.

Stopping Acquisition before completion
User can choose to stop the acquisition, turn off heating and Quit by clicking on 'Acquire Menu' and 'Emergency Stop'. The acquired data is discarded.

Viewing Saved Spectra
Saved Spectra can be viewed in TLResearchReader application or in Excel. To view in application, click on 'File' Menu and 'Open'. Select the filename to open and click ok.
The spectrum is retrieved and plotted. The Grid parameters including Dose Equivalent are updated. Also, Region Of Interest is highlighted in Red Colour. A sample is shown below:



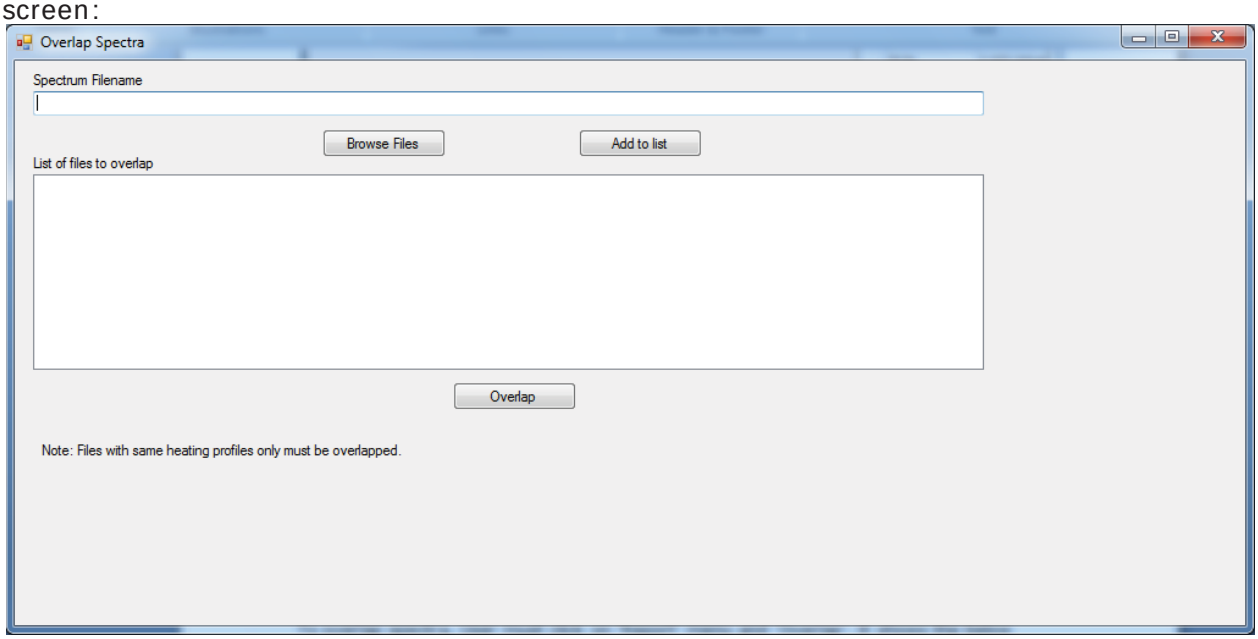
To view the file in MS Excel, click on 'Report' menu and 'View in Excel'.

Further processing of data, if required, can be done in MS Excel.

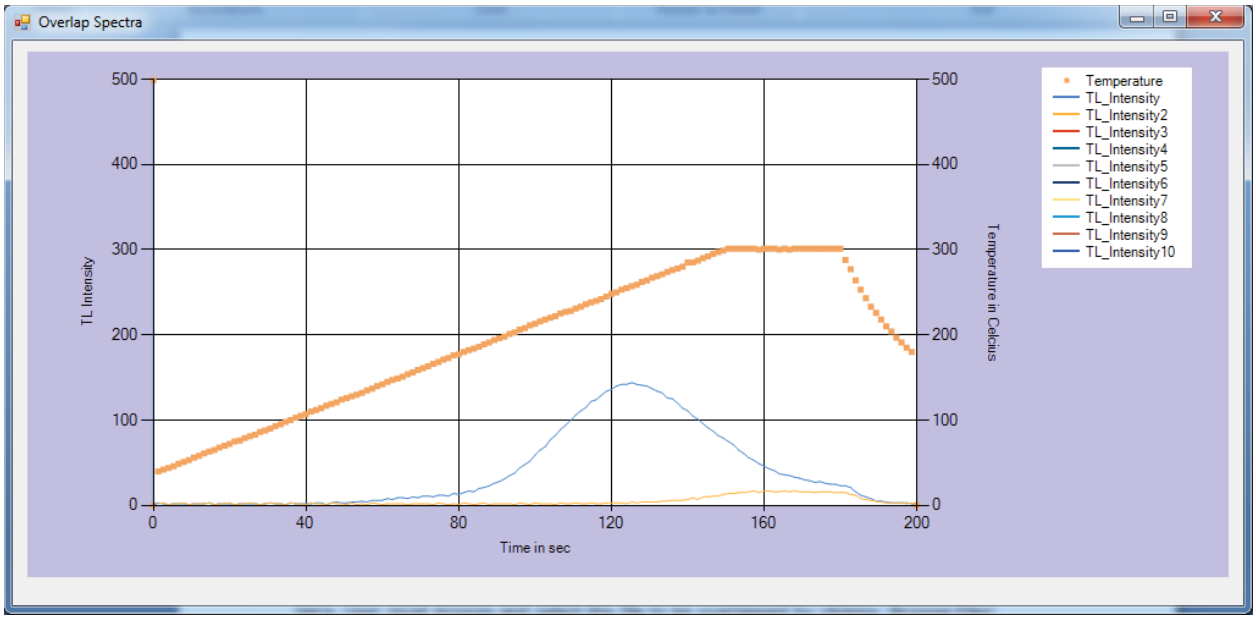
Overlapping up to 10 Spectra

This is a powerful feature that can be used to overlap spectra acquired using same Heating profile. User can visually compare and print the overlapped spectra.

To overlap spectra, User must click on 'Report' menu and 'Overlap'. It shows the below screen:



Here, User must browse and select the file to be overlapped by clicking 'Browse Files' button. Then, the file should be added to list by clicking on 'Add to list' button. Up to 10 files can be added to the list. Then, click on Overlap button. Given below is an overlap image of 2 files, which is saved as c:\Program Files\Nucleonix Systems\TLResearchReader\TLReader_Reports\Overlap.gif



About this Software

The version number of this software is displayed when ‘About’ menu is clicked. Please check with Nucleonix for the latest upgrades.

Maintenance and Customer Support

Periodic functional checks of system must be performed whenever possible. This can be done by Customer’s trained employees. Apart from this, PC must be kept free from Virus and backed up by UPS power.

Customer must enter into Annual Maintenance Contract after Warranty. This will entitle them for preventive maintenance checks, software upgrades, Re-Calibration, etc.

In case of any queries or issues with the software, you may contact us by email / phone / letter / fax. Details are given below:

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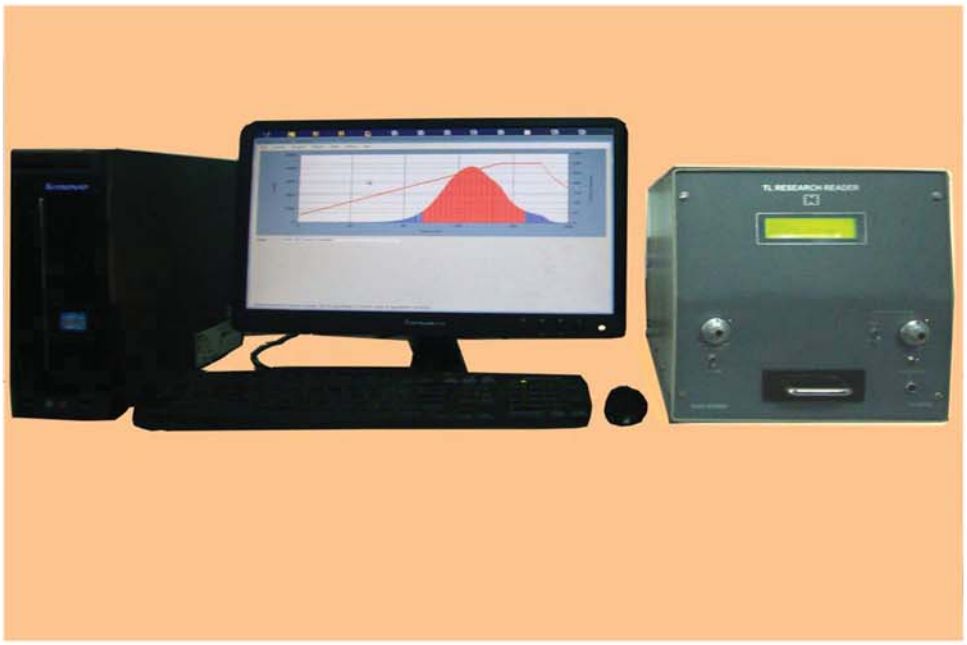
3.Thermoluminescence & Its basic applications

(45-126)

Thermoluminescence
Basic Theory
Applications and Experiments

A Guide for PG & Research studies in Thermoluminescenc



Authors By

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CHAPTER 1

Introduction

The spontaneous emission of light upon electronic excitation (e.g. excitation by ultraviolet radiation) is called photoluminescence. Luminescence is a common phenomenon among inorganic and organic as well as in semi-conductors. However, nonradiative relaxation processes may also predominant in some compounds. In those cases where spontaneous light emission does occur, its spectral and temporal characteristics carry a lot of important information about the metastable emitting state and its relation to the ground state. Luminescence spectroscopy is thus a valuable tool to explore these properties. By studying the luminescence properties we can gain insight not only into the light emission process itself, but also into the competing nonradiative photophysical and photochemical processes.

Luminescence is the emission of optical radiation (infrared, visible, or ultraviolet light) by matter. This phenomenon is to be distinguished from incandescence, which is the emission of radiation by a substance by virtue of it being at a high temperature (blackbody radiation). Luminescence can in occur in a wide variety of matter and under many different circumstances. Thus, atoms, polymers, inorganic, organic or Organo metallic molecules, organic or inorganic crystals, and amorphous substances all emit luminescence under appropriate conditions. The various luminescence phenomena are given their names, which reflect the type of radiation used to excite and to get the emission.

The main characteristic of luminescence is that the emitted light is an attribute of the object itself, and the light emission is stimulated by some internal or external process. This process is quite different to the incandescence seen in an ordinary light bulb filament. In this case the energy from a current of electricity is transferred directly to the metal atoms of the wire. This causes them to vibrate and hence heat up. The wire can then glow white hot, as in an incandescent light bulb. A characteristic of this type of light is that it is accompanied with a great deal of heat! The electrical energy is converted into radiation with an efficiency of about 80%, but the visible light being emitted is less than 10% of the total radiation. The remaining radiation is mainly in the form of infra-red heat. The spectrum of radiation emitted from a hot wire, or any other object, is not sensitive to the attributes of the object. All hot objects emit light and heat with very similar characteristics and this is well described by models based on a generic blackbody.

Light is a form of energy. To create the light another form of energy must be supplied. There are two common ways for this to occur, incandescence &luminescence.

INCANDESCENCE:

It is the light from heat energy. If you heat something to a high enough temperature it will begin to glow. When an electric stove's heater made up of metal is put in a flame, it begins to glow "red hot", and that is incandescence. When Tungsten filament of an ordinary incandescent light bulb is heated still hotter, by passing an electric current, it glows brightly 'white hot' by same means. The sun and stars glow by incandescence too.

LUMINESCENCE:

The term luminescence implies luminous emission which is not thermal in origin i.e. luminescence is 'cold light', light from other sources of energy, which takes place at normal and lower temperature.

In luminescence, some energy sources kicks an electron of an atom of its ground state (lowest energy) into an exited state (higher energy) by supplying extra energy, then as this excited state is not stable electron jumps back to its ground state by giving out this energy in form of light.

We can observe the luminescence phenomenon in nature like, in glowworms, fireflies, and in certain sea bacteria and deep-sea animals.
This phenomenon have been used in various fields by different scientist all over the world like, Archaeology, Geology, Biomedical, Engineering, Chemistry, Physics, and various Industrial Application for Quality Control, Research and Developments.

LUMINESCENCE AND STOKE'S-LAW:

In the process of luminescence, when radiation is incident on a material some of its energy is absorbed and re-emitted as a light of a longer wavelength (Stokes law). In the process of luminescence Wavelength of light emitted is characteristics of a luminescent substance and not on the incident radiation. The light emitted could be visible light, ultra-violet, or infrared light.

This cold emission i.e. luminescence, that does not include the emission of blackbody radiation thus involve two steps.

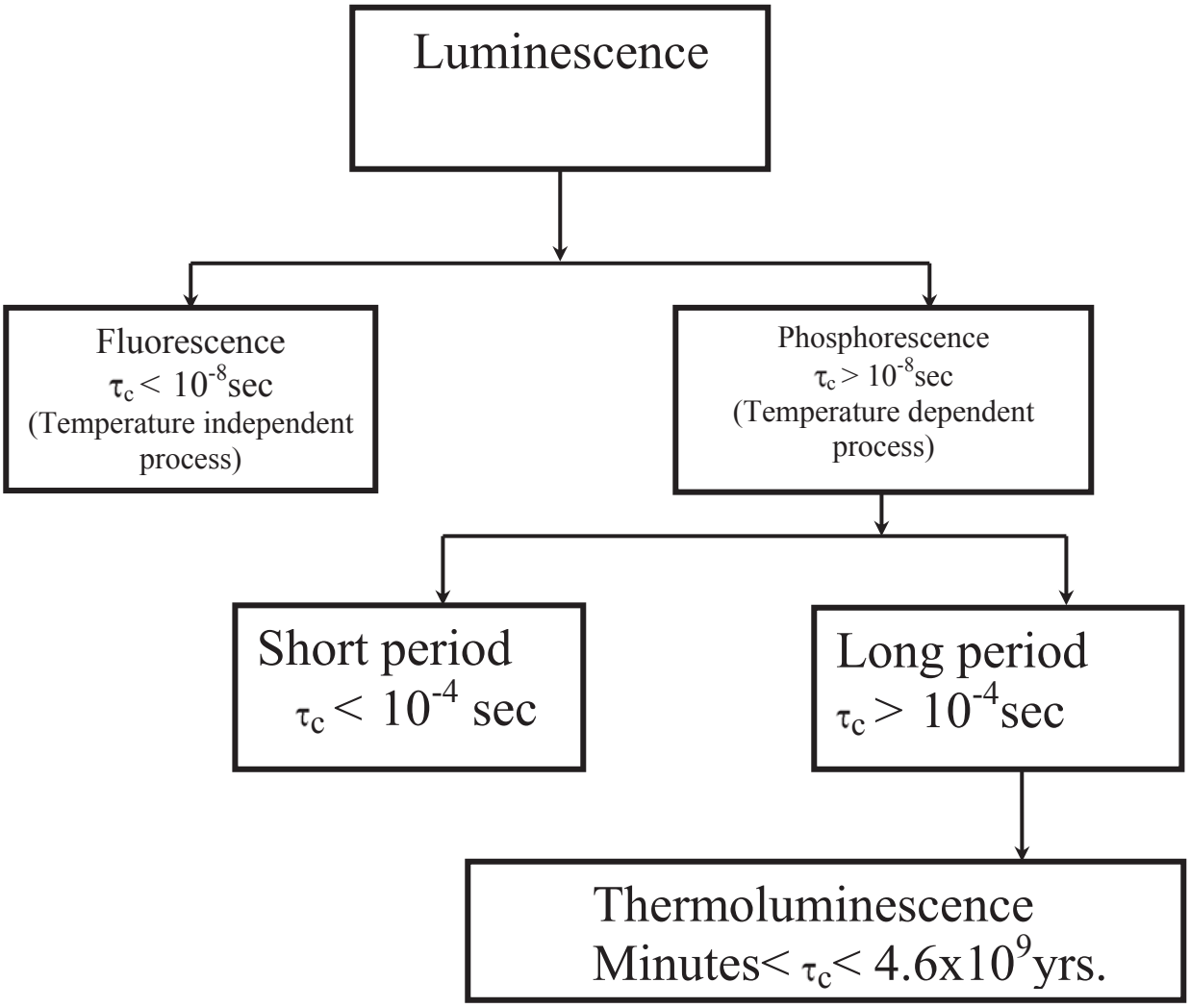
1) The excitation of electronic system of a solid material to higher energy state and
2) Subsequent emission of photons or simply light.

The emission of light takes place at characteristics time 'τ_c' after absorption of the radiation, this parameter allows us to sub classify the process of luminescence into fluorescence and phosphorescence as shown in figure1.

Thus, if the characteristic time 'τ_c' is less than 10^{-8}sec, then it is known as Fluorescence & if the characteristics time 'τ_c' is greater then that of 10^{-8}sec, them it is known as Phosphorescence.

A large number of substances both organic and inorganic show the property of luminescence, but principal materials used in various application of luminescence, involves inorganic solid insulating materials such as alkali and alkaline earth halides, Quartz (SiO_2), Phosphates, Borates, and Sulphate etc.

Luminescence solids are usually referred to as Phosphors.



The family tree of luminescence phenomena

The Fluorescence emission is seen to be spontaneous as 'τ_c'<10^{-8}sec, thus fluorescence emission is seen to be taking place simultaneously with absorption of radiation and stopping immediately as radiation ceases.

Phosphorescence on the other hand is characterized by delay between the radiation absorption and the time 't_{max}' to reach full intensity. Also phosphorescence is seen to continue for some time after the excitation has been removed.

If the delay time is much shorter it is more difficult to distinguish between fluorescence and phosphorescence. Hence phosphorescence is subdivided into two main types, namely, short-period ($\tau_c < 10^{-4}$sec) & long-period ($\tau_c > 10^{-4}$ sec) Phosphorescence.

Fluorescence is essentially independent of temperature, whereas decay of phosphorescence exhibits strong temperature dependence.

Fluorescence:

Fluorescence is the emission of light take place with a characteristic time $t_c<10^{-8}$ sec. in which emission takes place from an excited singlet state and the phosphorescence ($t_c > 10^{-8}$ s), in which emission occurs from an excited triplet state. To clarify between fluorescence and phosphorescence is to study the effect of temperature upon the decay of the luminescence. Fluorescence is essentially independent of temperature; whereas the decay of phosphorescence exhibits strong temperature dependence.

Several types of luminescence can be recognized. Some objects, when illuminated by light of one color, are stimulated to emit light of another color. This is called fluorescence. A common example is the chemical residue left behind in clothes by some types of washing powders. These powders emit visible light when stimulated by invisible ultra-violet (UV) light found in sunlight. Thus the clothes containing the residues appear brighter because of the combined effect of the reflected visible sunlight and the fluorescence from the washing powder residues. Another example is the fluorescent chemicals that coat the inside of fluorescent tubes. In these tubes the UV light comes from excited mercury vapour inside the tube. The energetic UV light excites electrons in the fluorescent chemicals which then emit visible light (with a small amount of heat) upon decaying back to their original states. The term photoluminescence is sometimes also applied to this type of luminescence which is stimulated by light of another colour.

Another example of fluorescence is in the modern machines for producing medical x-ray images. A screen that produces a lot of visible light called fluorescence when irradiated with x-rays is used to form an image which can then be photographed with films which are sensitive to visible light. This process is more sensitive than using the film to record the x-rays directly, thus minimizing the dose of x-rays to the patient. The following are few important applications of fluorescence

Applications of fluorescence:

The substances emitting the luminescence are called phosphors. Some phosphors are basically semiconductor describable in terms of energy band model. These are in biological forms. They may be in micro or macro forms. Professional have examined the PL of different materials and developed many macro and microscopic luminescence based devices. The brief account of applications of fluorescence is given below.

a) **Medical application**: Fluorescence is widely used in analytical work of various compounds present in cells lever's, kidney etc. The sensitivity and selectivity of PL in many micro system facilitates the professionals to estimate amino acids, protein's and nucleic acid in medico-logical works.

b) **Fluorescent Microscopy**: The microscopic components of the specimen exhibit PL on the interaction with UV or blue light. Fluorescence microscopes have been developed on this premise to examine and locate fine structure of such substances.

c) **Fluorescent screen**: Different luminescent materials under exposure of ionizing radiations; such as invisible alpha particles, electrons, ultraviolet light etc.

display visible emission of different colors. If the screen is prepared with luminescent material, it can be used to detect the presence of radiation field. This property of phosphors has been utilized in TV screen picture tubes, watch dials etc.

d) **Fluorescent Lamp**: The phosphors are pasted on inside wall of the lamp. UV light of 253.7 nm is generated through electric discharge. The phosphor absorbs the UV and through fluorescence emission it converts it in to visible light. The emission color of fluorescent lamp depends on nature of phosphor. Many varieties of fluorescent lamps are now available in market.

e) **Forensic Science**: Luminous emission from material is highly sensitive to nature, structure and impurity (or defect) present in the specimen. PL spectrum is as good as fingerprint of the specimen. Therefore, the comparison of the PL pattern of the ideal specimen with that of specimen with defect or in different condition provides lot of information. These facts are utilized in forensic science to detect and prosecution of criminals etc. It also evaluates physico-chemical condition of the specimen. It can be used for identification of substance in forensic science.

f) **Biological Application**: Plants contain fluorescent compounds in small concentration and distributed in specific locations. The examination of the fluorescence pattern of these compounds and their careful analysis leads to new technique to detect fungus in specimen, individual fluorescent chemical compound of biological origin. In addition to this it has helped to study phenomena of photosynthesis, by inspecting the variation of chloro- fluorescent at the beginning and end of period of the exposure of the plant material to light. The measurements of fluorescence polarization under various conditions lead to determine along the rotation of diffusion constant of proteins.

g) **Fluorescence in Chemical analysis**: If the different elements in the sample emits their characteristics lines by electron or X-ray bombardment, then these elements may be identified by analyzing the emitted radiation. Measurement of coating thickness on one chemical to another can be made by studying intensity of characteristics emission from material, Chemical behavior of liquids can also be studied by fluorescence method.

h) **Luminescent Devices as radiation services**: It includes indicator lamps, data punched type reader, position indicator, optomechanical programming, recondition equipments, thermo chrome motor controllers, advertisements etc.

i) **Mechanical behavior of materials through Luminescence**: Luminescence is a structure sensitive phenomenon, which is very sensitive to detect pattern inside the lattice of the materials. One may find out defect, patterns in host matrix by examining fluorescence spectra.

j) **Fluorometry**: In this technique, re-emitted visible emission from the material is analyzed critically, which gives informative about the material. It is very good technique. It is used in many fields. (a) Impurity analysis is done through comparison of PL spectra of specimen with that of standard spectra. This technique is widely used in tablet industry in medical field. (b) The detection and assessment of several fluorescing compound in the same solution is also possible. (c) Fluorometry is also useful in biology and medicine. It gives idea regarding vitamin deficiency, estimation of blood, urine and concentration of hormones. In chromatographic separation; detection of Poison and identification of strain i.e. pus, blood and urine.

Phosphorescence:

In some materials, electrons excited by the original radiation can take some time to decay back to their ground states. The decays can take as long as few hours to few or days. This type of fluorescence is called phosphorescence and the material continues to emit visible light for a while after the original radiation has been switched off. If the duration is very short, around 10^{-4}s, then the material is a short persistence phosphor. If it lasts for seconds or longer it is a long persistence phosphor. Objects displaying phosphorescence are sometimes said to be luminous. Most luminous toys, stickers and watch dials are coated with long persistence phosphors.

Bioluminescence is the result of certain oxidation processes (usually enzymatic) in biological systems like fireflies, jellyfishes etc.,

Cathodoluminescence:

Cathodoluminescence is due to emission of light during electron irradiation (CRO & TV Screen Phosphors). In the beginning of the last century, it was observed that invisible cathode rays, produced by electrical discharges in evacuated tubes, produced light when they struck the glass walls of the tube. The modern name for cathode rays is electrons and this type of luminescence is has retained the name cathodoluminescence. This is a very useful form of luminescence. Beams of electrons are used for many purposes. The electron microscope employs beams of electrons to produce high resolution images of small specimens. In some cases, the beam produces cathodoluminescence from the specimen. This is particularly useful for the study of minerals in rocks where the presence of transition metal trace elements can cause the mineral to give of a distinctive colour light. Often the presence of the trace element cannot be detected in any other way. Also, the ubiquitous video display tube also employs beams of electrons to selectively excite red, green or blue phosphors to display colour images. This is such an efficient process that despite continuing revolutions in the semiconductor industry, the video display industry remains dominated by the nineteenth century technology of the video tube.

Chemiluminescence:

Chemiluminescence is produced as a result of a chemical reaction usually involving an oxidation-reduction process. The most common mechanism for such an emission is the conversion of chemical energy, released in a highly exothermic reaction, into light energy in the visible region. In some chemical reactions, energy can be transferred to electrons in the chemical bonds. As these electrons decay down to lower excited states, they emit light. Some

of these reactions proceed slowly, so the light can be emitted for a considerable time. This is known as chemiluminescence. This is distinct from more vigorous chemical reactions where so much heat is released that the chemicals actually catch fire or otherwise glow red hot. This is nothing more than incandescence. Chemiluminescence is displayed by a variety of organisms and the chemical reaction usually involves the oxidation. This type of light emitting chemical is called luciferin. This is an organic molecule with two hydrogen atoms attached, symbol LH_2. With the aid of the molecule responsible for the storage of energy in cells, adenosine triphosphate (ATP) and a special catalyst molecule (the enzyme luciferase), the luciferin is oxidized to L=O in an excited state. When it changes into the ground state a visible light photon is emitted. One visible light photon alone is emitted as each molecule of luciferin is oxidised, so this process is really light without heat. The light is typically light blue in colour, although differing chemical environments can modify the colour. It is believed that this light producing process evolved as a small side branch of the main oxidation-reduction reactions that extract energy from nutrients. Some synthetic molecules, such as Luminol (5-aminophthalhydrazide) and Cyalume are the basis of commercially available chemoluminescent products. Remarkably, some of the steps that lead to the production of light from these chemicals remain to be fully understood.

Electroluminescence:

Electro-luminescence is the efficient generation of light in a non-metallic solid or gas by an applied electric field or plasmas. Another type of electro-luminescence is that produced by some crystals when an electric current passes through them. In this case the current of electrons excites electrons that occupy energy levels involved with chemical bonds inside the crystal. When the excited electrons decay back to their ground state they emit visible light. This phenomena known as electroluminescence. There are several different methods of exciting electroluminescence from a crystal. In one method, AC voltages applied to special panels produces light. About 40 years ago, it was thought this sort of light would replace ordinary light bulbs for many domestic applications. This was because electroluminescent coatings could be applied to walls, ceilings, even curtains! There was also virtually no limit to the range of colours that could be produced. Unfortunately, several practical difficulties could not be overcome, such as efficiency, and that high frequency AC was required to excite the luminescent material. However, the light emitting diode (LED), operating on a different principle, has now become a widely used application of electroluminescence including the mobile displays apart from LEDs.

Ionoluminescence:

A more exotic method of producing luminescence is the visible light produced when fast ions collide with organic, in-organics compounds. This is called ionoluminescence. An early application of ionoluminescence was to luminous clock dials. These relied upon a rather hazardous method of making light that involved radioactivity. A radioactive material, such as radium, was mixed with a material that displays luminescence, such as zinc sulphide. As the radium decays, it emits alpha particles and other radiation. This excites electrons in the luminescent material to give off light. This is very handy, since the light persists indefinitely, limited only by the half-life of the radium isotope used, ^{226}Ra, which is 1600 years. However, the manufacturing process for such watch dials gave radiation exposure, mainly internal exposure- to workers involved in this work in 1920s and 1930s. At a luminous dial painting factory as a result of licking their paint brushes to get a fine brush point.

Lyoluminescence :

Lyoluminescence is the phenomenon of light emission during the dissolution of previously irradiated solids in suitable solvents.

Mechanoluminescence (triboluminescence or piezoluminescence):

Mechanoluminescence is due to the emission of light on applying an external mechanical energy. It could be excited by cutting, cleaving, grinding, rubbing, and compressing or by impulsive deformation of solids.

Optically Stimulated Luminescence (OSL) Photostimulated Luminescence (PSL) :

OSL and PSL offers an alternative technique to conventional X-ray radiography, which consist of a photographic film and an intensifying screen. They are adoptable to digital radiography systems which are based on the conversion of the X-ray image pattern into digital signals utilizing laser beam scanning of an optically stimulable imaging plate.

Radioluminescence (or scintillation) :

Radioluminescence is produced by ionizing radiations. Some polymers contain organic molecules which emit visible light when exposed to such radiations as X-rays, gamma rays or cosmic rays, and thus act as detectors for high energy radiations.

Sonoluminescence:

Sonoluminescence is the emission of light due to the excitation by Sound waves including ultrasonic waves.

The Mechanism of Luminescence:

The most important characteristic of luminescence is that it is an attribute of the material producing the light, and not the method used to excite it. The production of luminescence from a solid material can be understood from the band theory for solids. This is a theory based on elementary atomic physics and quantum mechanics. The theory is briefly introduced here.

An isolated atom carries its collection of electrons in its orbitals surrounding the nucleus. These orbitals are analogous to the orbits of the planets around the Sun, although in that case gravity binds the system instead of the electromagnetic force as in an atom. The electrons can only occupy special orbits that allow them to orbit without loosing energy. These allowed orbits may be determined from the laws of quantum mechanics. Also, owing to the fact that electrons can share their orbitals with at most one other electron of the opposite spin (the Pauli Exclusion Principle), some electrons must occupy orbitals far from the nucleus because the lower energy orbitals closer to the nucleus are already occupied.

Vacancies can be created in occupied orbitals by dislodging the occupied electron with a pulse of radiation such as from a photon, a fast electron or some other process. When this occurs, an electron from an outer level will fall down to reoccupy the inner, lower energy,

level. The excess energy is radiated away as a photon. For some transitions, this photon can be within the visible spectrum. Gases in discharge tubes that are bombarded by currents of electricity can display a spectrum characteristic of the transitions between the allowed energy levels in the solitary gas atoms.

In a solid, the situation is more complicated. When individual atoms are joined together to make a solid, the atoms must be pushed relatively close together. When this happens, the outer electron orbitals begin to overlap. Since no more than two electrons can occupy the same level, the energy levels begin to split into sub-levels. If six atoms are joined together to make a small lump of material, the orbital of the outermost electron overlaps with the adjacent atoms and splits into six to accommodate all electrons. These new orbitals are associated with the entire lump, rather than just a single atom. Millions of atoms are joined together to make a sizable lump of material. The outer orbitals overlap and split into a number of sub-levels, all with slightly differing energies.

In practice, the energy levels are so close together, and there are so many of them, we can speak of the orbital now consisting of an energy band.

On a small scale, the solid consists of a crystal with all atoms occupying lattice sites. Some normal solids, of interest here, consist of large assemblages of microscopic crystals. The luminescent properties of the solids depend on the properties of the crystal structure.

The formation of energy bands occurs regardless of whether the energy levels are occupied by electrons or not. Therefore, in a typical material, the outermost electrons occupy a band called the valence band, above which is the next higher energy band called the conduction band. The energy difference between the highest energy (top) of the valence band and the lowest energy (bottom) of the conduction band is called the band gap energy.

If the valence band is completely full of electrons and conduction band is completely empty, the material is an insulator, since to conduct electricity the electrons must pick up energy and move to a slightly higher level. Since all available levels in the valence band are full, they cannot do this, and the material is an insulator.

If the valence band is only partially occupied, then the material is an electrical conductor since there are free energy levels available for the electrons to carry the electric current. Owing to the fact that the valence band is formed from the outermost occupied orbitals of the atoms, which can contain either one electron or two electrons of opposite spins, the valence band in any material is always either entirely full (insulators), or just half full (conductors).

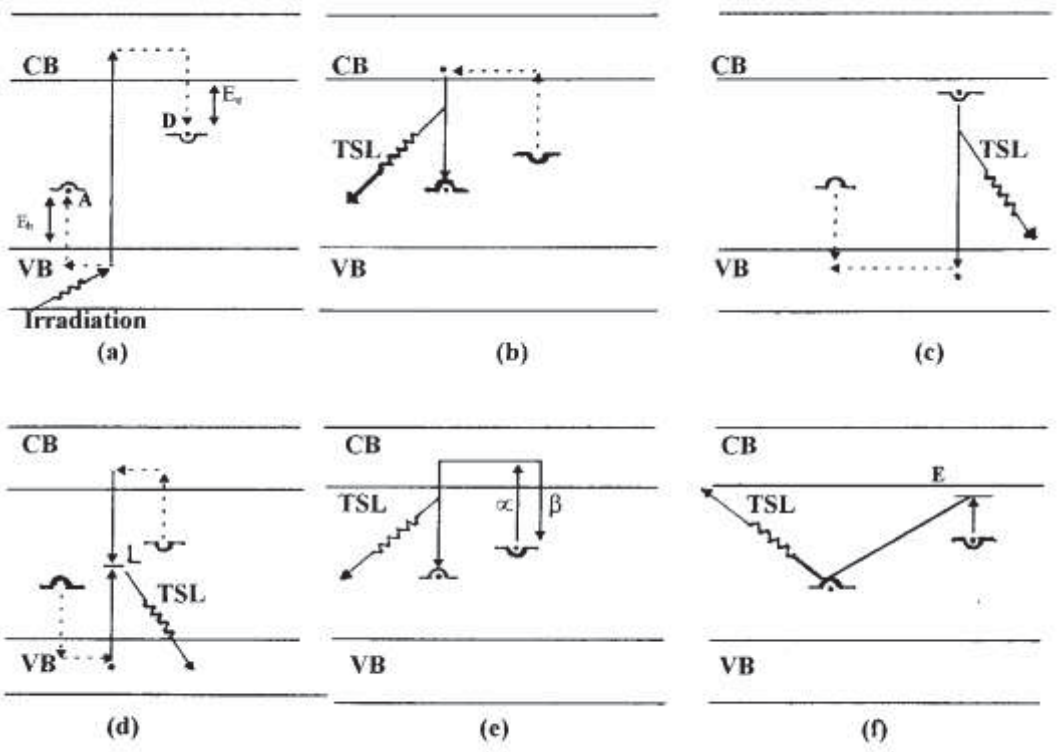


Fig l.1 Processes involved in radiation induced electron/hole trapping and subsequent recombination on thermal stimulation with associated luminescence emission.

VB- Valence band,
CB - Conduction band,
Eh - Trap depth for hole,
Ee - Trap depth for electron,
L - Luminescent center, A - Hole trap and D - Electron trap.

(a) On gamma irradiation, electrons and holes are produced and trapped at electron hole traps.
(b) On thermal stimulation, trapped electron is released and recombines at trapped hole site.
(c) e-h recombination at trapped electron site.
(d) e-h recombination at luminescent center site.
(e) Process of de trapping and re trapping(second order kinetics, a – de trapping probability and p- re trapping probability) ;
(f) e-h recombination via an excited state 'E' and tunneling.

In some materials, the gap between the fully occupied valence band and the empty conduction band is very narrow. So narrow in fact that ordinary heat energy at room temperature can promote electrons from the valence band into the conduction band. Such materials are semiconductors. These are generally poor conductors compared to metals.

When any solid material is excited by energetic radiation, electrons can be excited out of the valence band into the conduction band. This leaves behind a hole in the valence band. The electron in the conduction band can dissipate excess energy as small amounts of heat until it

reaches the lowest energy (bottom) edge of the conduction band. It can then fall back into the hole in the valence band, radiating the energy difference as a photon.

Band gap energies, and associated band gap transition wavelengths, for some semiconductors. 'd' indicates that a transition directly across the band gap can conserve momentum and is therefore possible. 'L' indicates that a direct transition is not possible and a lattice vibration, or phonon, is necessary to conserve momentum and so only indirect transitions are possible.

Doping:

It is known fact that the band gap energies of few materials have band gaps where the band width corresponds to the visible spectrum. However, materials with a relatively wide band gap can be made to luminesce in the visible. This is possible by the addition of different atoms or imperfections into the crystal. The additional atoms, called dopants have a different electron orbital structure compared to the host crystal lattice. Therefore, in regions of the crystal around the dopant atom, additional energy levels become available. That is, within the forbidden band gap of the material, energy levels can co-exist that can accommodate electrons or holes. These levels can be close to the conduction band, in which case the dopant is called a donor, or close to the valence band, in such case it is called an acceptor. Transitions between these levels can give rise to visible luminescence in such case the dopant is known as an activator. In most cases, the activator is present in extremely small concentrations, ranging from as much as one dopant atom in 5000 host atoms down to as little as one dopant atom in 1 million host atoms.

Sometimes the excited electron can find other ways to dissipate its energy. Several non-radiative recombination mechanisms are also possible. These are usually associated with defects in the crystal, or levels in the middle of the band gap, called deep levels, introduced by impurities called inhibitors. Still other defects in the crystal can result in shallow levels which are close to the edge of either the valence or conduction bands. Shallow levels in the band gap can trap the excited electrons. Certain characteristics of these shallow level prevent the electron from decaying immediately back into the valence band. Instead the decay may only occur after a very long time. However a small amount of heat may dislodge the electron back into the conduction band from where it can readily decay back to the valence band. This is the mechanism behind the technique of thermoluminescence.

Thermoluminescence (TL) or Thermally Stimulated Luminescence (TSL):

TL or more specifically Thermally Stimulated Luminescence (TSL) is stimulated thermally after initial irradiation given to a phosphor by some other means (α- rays, β -rays, γ - rays, UV rays and X-rays). Thermally stimulated luminescence (TSL) is the phenomenon of emission of light from a solid which has been previously exposed to ionizing radiation under conditions of increasing temperature. Unlike other luminescence process such as Electroluminescence, Chemiluminescence, here heat is not an exciting agent, but it acts only as a stimulant. Hence it is better known as thermally stimulated luminescence (TSL). Excitation is achieved by any conventional sources like ionizing radiation, α-rays, β-rays, γ-rays and UV rays and X-rays. TSL is exhibited by a host of materials, glasses, ceramics, plastics and some organic solids. By far insulating solids doped with suitable chemical

impurities, termed as activator, are the most sensitive TL materials. The band theory of solids is normally used to explain this phenomenon. When a solid is irradiated, electrons and holes are produced. The defects in the solid results in the presence of localized energy levels within the forbidden gap. On irradiation, electron and holes can be trapped at these defect sites. When the solid is heated, these trapped electrons/holes get enough thermal energy to escape from the trap to the conduction band (or valence band). From here they may get re-trapped again or may recombine with trapped holes/electrons. The site of recombination is called recombination center. If this recombination is radiative, then center is called luminescence center. Alternatively a trapped hole can be released by heating which can recombine with a trapped electron resulting in luminescence. These features are shown diagrammatically in **Fig.1.1**. It is not required that all charge recombination should result in luminescence, they may be non- radiative too. The plot of intensity of emitted light versus the temperature known as a TL glow curve. A glow curve may exhibit one or many peaks depending upon the number of electron/hole traps with different trap depths, present in the lattice. These peaks may or not be well separated. The position, shape and intensity of the glow peaks therefore are characteristic of the specific material and the impurities and defects presents. Therefore each TSL peak corresponds to the release for an electron (or hole) from a particular trap level within the band gap of the material. The nature of the TL glow peaks gives information about the luminescent centers present in the material. It may be mentioned that TSL is highly sensitive to structural imperfections in crystals. Defects densities as low as 10^7/ cm^3 also can give measurable TSL if radiative recombinations are dominant whereas techniques such as EPR and OAS are sensitive only for relatively higher defect concentrations such as 10^{12}/ cm^3. The first step towards understanding the mechanism for TSL glow peaks is the identification of the trapping center and the recombination centers for the observed light emission. Apart from being a tool for the study of defects in solids, TSL has also found widespread use in radiation dosimetry, archeological dating of pottery, ceramics, minerals etc; and meteorite research.

Phase Change Thermoluminescence (PCTL): Some of the organic molecules, agricultural products and few minerals (zeolites) containing water molecules in their structure do exhibit the thermoluminescence without prior irradiation. This phenomenon is known as Phase Change Thermoluminescence (PCTL). Using this phenomena one can find the phase transitions of that material.

Thermoluminescence (TL), more appropriately called thermally stimulated emission (TSL), is the emission of light from an insulator or semiconductor when it is heated. But it must have absorbed high energy radiation prior to its stimulation by heat.

Thus three essential ingredients necessary for the production of Thermoluminescence are:

- The material must be an insulator or a semiconductor (metals do not exhibit luminescent properties)
- The materials must have at some stage absorbed energy during exposure to radiation.
- The luminescence emission is triggered by heating the materials

One particular characteristics of thermoluminescence is that, once heated to excite the light emission, the materials cannot be made to emit thermoluminescence again by simply cooling the specimen and again reheating. In order to exhibit the luminescence the material has to be re-exposed to radiation and then raising the temp will once again produce light emission.

BASIC PHYSICAL PRINCIPLES

Phosphorescence and Thermoluminescence :

Luminescence is the emission of light from a material following the initial absorption of energy from an external source – e.g., ultraviolet or high-energy radiation. The emission can be categorized as either fluorescence or phosphorescence, depending upon the characteristic lifetime between absorption of the excitation energy and emission of the luminescence. The distinction between the two processes is not always clear and is perhaps most easily made using the temperature dependence of luminescence. Consider a ground-state energy level e, illustrated in figure-2 (a). Fluorescence is the emission of light that follows the excitation of an electron from g to e and its subsequent return to level g. on the other hand if the return to the ground state is delayed by a transition into and out of a metastable level m, then delays between excitation and emission can result (figure-2(b)), and in this case the process is known as phosphorescence. If the transition into level m occurs at a temperature T, where the energy E of separation between m and e is such that E> several kT (k is Boltzmann's constant), then the electron is likely to reside in m for a considerable period. In this case, assuming a Boltzmann distribution of energies, the probability PL per unit time for thermal excitation from the trap is exponentially dependent upon temperature according to Eq. (a), and the time between excitation and final relaxation back to the ground state can be considerably delayed by the residence of the electron in the metastable state. The temperature dependence described by Eq. (a) provides a means for distinguishing between the weakly temperature-dependence process of fluorescence and the strongly temperature dependent process of phosphorescence.

If the metastable level is an electron trap, at an energy E_t below the conduction band. The activation energy for the phosphorescence $E = E_t$ for typical numerical values of $E_t = 1.5$ eV and $s = 10^{12}$ s^{-1}, the calculation of p at 298 K using Eq.(a) indicates that, for all practical situations, the trap would never thermally release its trapped electron, and as a result phosphorescence would never be observed at this temperature. However if the temperature were to be raised, the temperature may be reached at which the p is high enough to ensure that electron release occurs and luminescence is observed. For e.g., at T = 300 K and using the above values for the E and s, one can calculate the lifetime $\tau = 1/p$ of 5.06×10^5 years, in contrast at 500 K, T = 0.36 sec. thus, consider rising the temperature of the system at some arbitrary rate $\beta = dT/dt$. As the T rise so p increases, producing enhance luminescence emission. Unlike phosphorescence, which is normally assumed to occur at a fixed temperature, this emission is stimulated in a non-isothermal situation and is thus termed as thermally stimulated luminescence (TSL), or more popularly thermoluminescence (TL). As the temperature continues to rise, so the TL intensity increases until such time as the population of trap electron in metastable state is sufficient depleted, at which point the TL intensity decreases with further increase in the temperature.

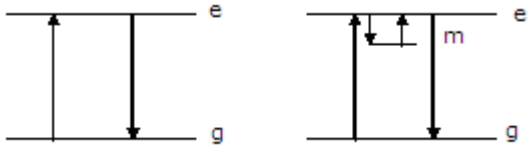


Figure-2 (a) & (b)

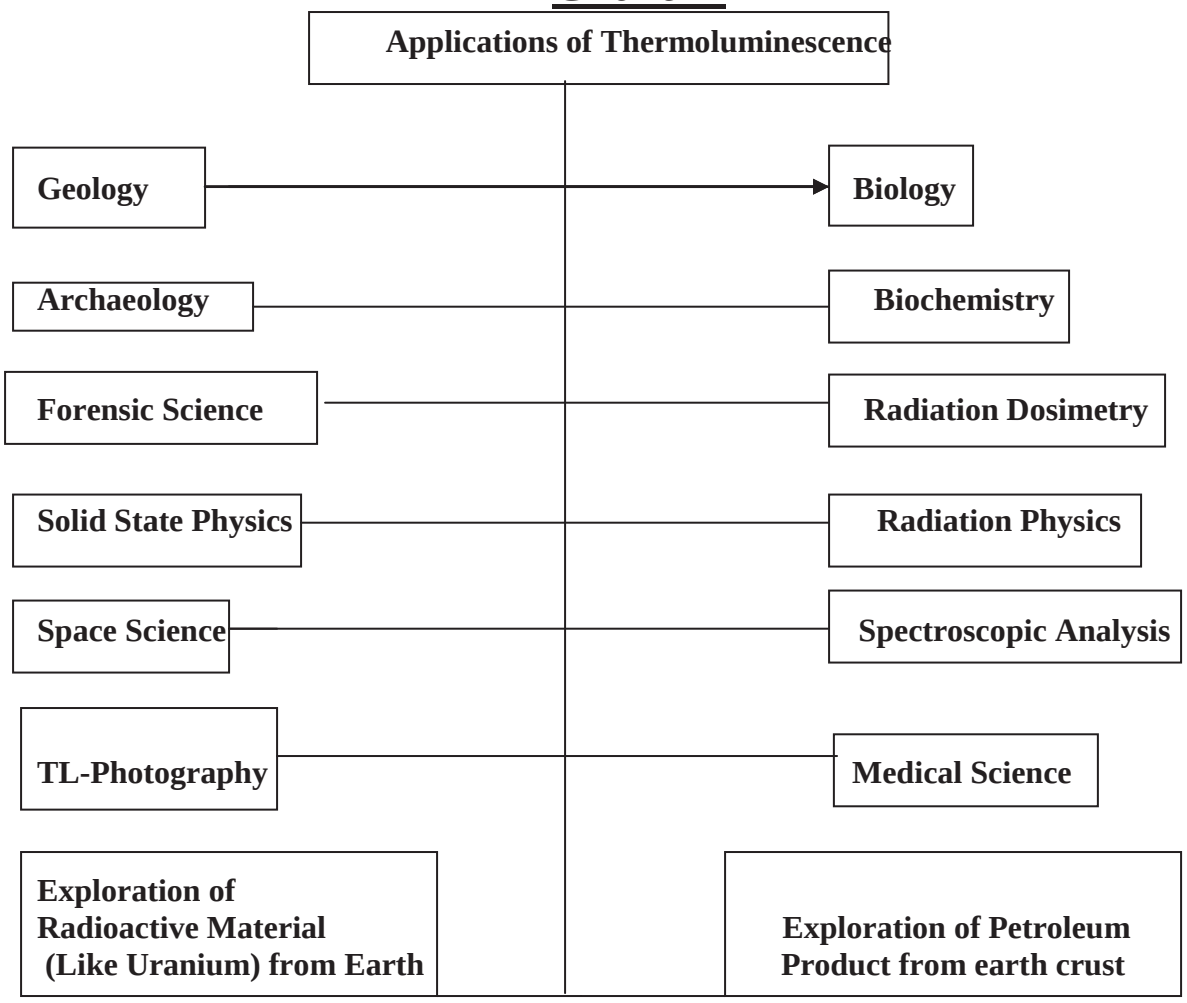
the result is the characteristics TL peak (glow peak) for which the temperature at the peak maximum is related to trap depth E_t, the frequency factor s, the rate of heating β.

Here we see the metastable localized level (level 1) at an energy E_t below the conduction band and a deep level (level 2) assumed to reside below the system Fermi level (E_f). Prior to irradiation level, is assumed to be empty, and level 2 is assumed to be full. During irradiation electrons are excited across the material's band gap and become trapped at level likewise, holes become localized at level the result is a non equilibrium excess of electrons above E_f, and deficiency of electrons below E_f.

Application of Thermoluminescence:

The phenomenon of TL has been extensively studied by many investigators. The understanding of the mechanism of occurrence of thermally stimulated emission is the important field of fundamental research. Many researchers have suggested their views for TL mechanism for pure and impurity activated materials. With expanding knowledge of solid state physics, it is a topic of research to give latest plausible mechanism of TL. However, the present understanding of TL has explored very high application potential of it in various fields. The modernization and development in the instrumentation; and better understanding of TL have helped the professional to solve their problems in many fields. The applications of the TL are summarized in the following **chart- A.**

Chart-A



Basic concept of Thermoluminescence [TL OR TSL]:

Thermally stimulated luminescence (TSL) is the phenomenon of light emission during warming a previously irradiated substance with uniform heating rate. When a material is exposed to ionizing radiation like; alpha, beta, gamma and X-rays or UV-rays or when it undergoes certain chemical reactions or mechanical stress, a certain percentage of the liberated charge carriers (electron and holes) may be trapped at certain imperfections in the lattice, which are called traps. If these traps are deep enough, the charge carriers remain trapped for a long time [thousands of years] before they are released by sufficient stimulation. This stimulation can be achieved by supply of optical or thermal energy to these excited solids.

The return of these trapped charge carriers to a stable state due to the stimulation by external energy (e.g. heat) is always associated with the release of absorbed energy (by the charge carriers), mostly in the form of heat. A small fraction of the absorbed energy is also released in the form of light during this process. This form of emission of light is called Thermoluminescence (TL). The TL from the material is very sensitive to;

i) The amount and nature of impurity,
ii) Thermal history,
iii) Pre-thermal, mechanical and radiation effect,
iv) Size of material particle,
v) Crystallization history and
vi) Defect pattern present in the material.

Theory states that no electron can exist in the material with energy states falling in the forbidden gap. When the material is excited by any ionizing radiations (**Fig.1.1.a**) some electrons (originally in the valence band) are excited and they attain energy states corresponding to the conduction band. Normally, these electrons cannot remain excited indefinitely, that is the lifetime of an electron in the conduction band is very short and the electron attains its ground state immediately giving away the energy to warm up the crystal lattice or in the form of light.

However, an impurity atom (with an appropriate ionic size and charge) present in the material can have energy states in the forbidden band. These are the metastable energy states having appreciable lifetime. An excited electron can find itself in this state, rather than getting back to its normal valence band state. Now, one says an electron is 'trapped'. In analogy, it is also visualized that a 'hole' (absence of an electron) is trapped at an energy state very close to the valence band. Depending upon the energy level of the electron trap with respect to the conduction band (or the hole trap with respect to the valence band)-called the trap depth.

This stage corresponds to a energy storage after the initial excitation of a material .If now the material is warmed, the heat supplied is able to stimulate the electron out of the traps (de-trapping) and the electrons return to the ground state, if the conditions are favorable (for example, the particular atom has a light emitting property) for the emission of light in this 'return process' then thermoluminescence occurs (**Fig.1.1 b**). Alternatively, a hole may be excited into the valence band where it wanders until it combines with an electron at the trapped counter- part emitting the TSL. (**Fig. 1.1 c)**.

If the traps are not very deep, de-trapping and recombination may already occur at a substantial rate around room temperature resulting in a short half-life of the stored energy. This is called phosphorescence but strictly speaking it is thermoluminescence at the room temperature. Only, if the traps are the deep enough to result in sufficient storage stability at room temperature (half-lives of trapped electrons at least several months normally corresponding to glow peak temperature greater than about 150^{o}C), the effect becomes of dosimetric interest .The glow curve generally exhibits many peaks, each corresponding to a trap with a different energy depth.

In many phosphors it is possible that the electrons and holes are de-trapped more or less simultaneously and they recombine at an entirely new site (**Fig.1.1 d**) which is called luminescence center or recombination center. The TL glow curve will in this case represent an effective thermal activation energy needed by the trapped electron / hole to surmount a potential barrier between the trap and recombination center. In reality, a trapped charge when de-trapped has a finite probability of getting re-trapped as in Fig.1.1e.When this re-trapping probability is significant, the shape of the glow curve is different from the case when it is absent. Also the recombination probability for the de-trapped charge carrier may in most cases charge with time (i.e. as the heating proceeds) depending on the number of available unused recombination centers. Such a process is called a second order or bimolecular process usually while the simplest case where the recombination has a constant probability with time, is called a first order or monomolecular process. There are also practical situations where the de-trapped charge carriers recombine directly without having to be excited into the conduction / valence bands. This is a, case of TL involving isolated luminescence center and process follows first order kinetics (**Fig.1.1 f**). All the foregoing discussions take into account only the ionization effects of the excitation irradiation; one should not however forget about the displacement effects resulting from elastic/inelastic collisions of the atom of the phosphors with the impinging radiation. This effect is more significant for the case of particular radiations (like alpha, beta, gamma, neutron, cosmic rays). The important thing about this displacement effect is that atoms are physically moved which results in the creation of interstitials, and vacancies. In relation to thermoluminescence, these constitute defects, which have potential to influence the trapping and emission processes.

Configuration co-ordination curve Model:

Luminescence in atomic gases is adequately described by the concept of atomic spectroscopy, but luminescence in molecular gases, in liquids and in solid introduced two major new effects, which need special explanation. One is that the emission band appears on the long wavelength (low energy) side of the absorption band, the other is that emission and absorption often show as bands hundreds of angstroms wide instead of as the line found in atomic gases. Both of these effects may be explained by using the concept of configuration co-ordinate curves shown in Fig.1.2. As in the case of atomic gases the ground and excited states represent different electronic states of the luminescence centers, that is the region containing the atoms or electrons or both involve in the luminescent transition. On these curves energy of the ground and excited states is shown to vary parabolically as some configuration co-ordinate, usually from the luminescent center to its nearest neighbors. There is a value of the co-ordinate for heat energy is given up when the system goes from D back down to A. This loss of energy in the form of heat causes the energy associated with the emission C to D to be less than that associated with the absorption A to B.

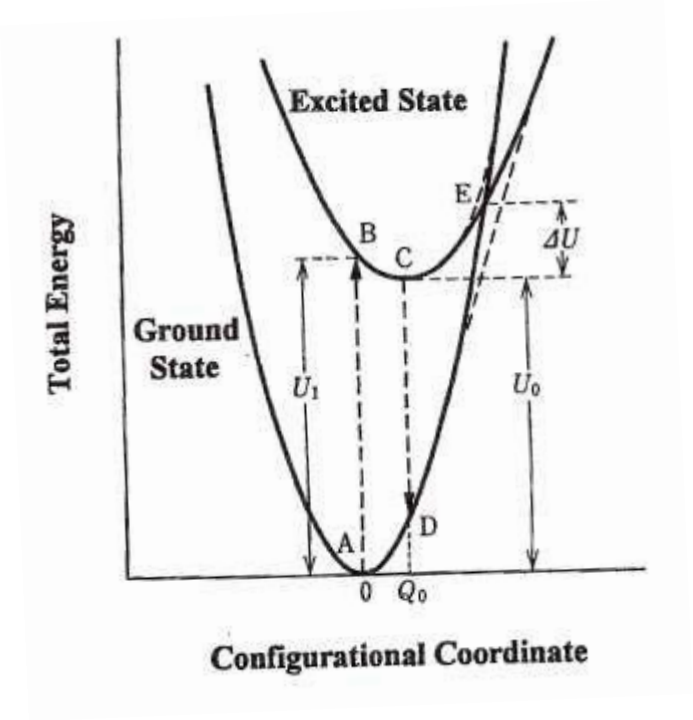


Fig. 3

Figure: 3. A schematic illustration of a configurational coordinate model. The two curves are modified by repulsion near the intersection (broken lines). The vertical broken lines A to B, B to A and C to D and D to C indicate the absorption and emission of light, respectively.

When the system is at an equilibrium position, such as C of the excited curve it is not at rest but migrates over a small region around C because of the thermal energy of the system. At the higher temperatures these fluctuations cover a wider range of the configuration co-ordinate. As a result of emission transition is not just to point D on the ground state curve but covers a region around D. In the vicinity of D the ground state curve shows a rapid change of energy, so that even a small range of values for the configuration co-ordinates leads to a large range of energies in the optical transition.

This explains the broad emission and absorption bands that are observed. An analysis of this sort predicts that the widths of the band (usually measured in energy units between the points at which the emission or absorption is half its maximum value) should vary as the square root of the temperature. For many systems this relationship is valid for temperatures near and above room temperature.

Two other phenomena, which can be explained on the basis of the model described in Fig. 1.2, are temperature quenching of luminescence and the variation of decay time of luminescence with temperature. On the scheme of Fig 1.2 this is interpreted as meaning that the thermal vibrations become sufficiently intense to raise the system to point E. From point E the system can fall to the ground state by emitting a small amount of heat or infrared radiation. If point E is at an energy EQ above the minimum of the excited state curve, it may be shown that the efficiency 'η' of luminescence is given by the following equation.

$$\eta = 1+C \exp^{(-EQ/KT)}$$

where C is a constant, K is Boltzman constant and T is the temperature on the Kelvin scale.

The temperature quenching tends to occur most strongly for centers that would have stayed in the excited state for a relatively long period of time. As a result, the decay time of the emission that occurs in this temperature region is largely characteristic of centers in which transitions to the ground state have been rapid; therefore, the decay time of the luminescence is observed to decrease.

Applications of Thermoluminescence to Archaeology:

Thermoluminescence technique has been found to be highly successful in dating ancient pottery samples. This method is suitable because of the following reasons:

i) It gives the exact date of kiln firings of the sample (the other methods mostly depends on the shape and style of the pottery and hence correlate with the civilization to which it belonged).
ii) TL dating is possible even beyond 30000 years, but minimum age is 50years with an accuracy of ±1 year.
iii) Authentication and detection of forgery can be quickly and easily done by using this method.

The TL/OSL dating is done from a quartz grain which is collected from pottery or brick by reading the TL-output. The TL from the specimen is mostly due to TL sensitive mineral inclusions (mostly quartz) in the host clay matrix of the pottery. The technique of the dating pottery is very much similar to that done in geological samples. In archaeology, a more precise and definite event is the basis – the kiln firing. The pottery must have fired in the kiln some time in the long past. That event is considered to be the starting of the 'TL clock ' for archaeological dating. Whatever TL has been stored earlier in the mineral inclusion due to internal and external irradiations over the geological times (since crystallization) is considered to be erased during the kiln firing.

After the onset of the 'TL clock' (kiln firing) the pottery starts building up TL due to internal irradiation from radioactive emanation of uranium (U), thorium (Th), and potassium (K), contents in the clay and external radiations from the cosmic background at the excavation site. Typically the total irradiation rate is of the order of 1 rad per year of which the major part is from internal radiations and the remaining due to soil irradiation and cosmic rays. Once an accumulated TL in the specimen has been measured and expressed in terms of absorbed dose by proper calibration techniques and if the total irradiation rate for the specimen could be established, the archaeological age can be obtained by simply dividing the former by the latter.

$$\text{i.e. Age} = \frac{\text{Accumulated dose}}{\text{Annual dose rate}}$$

But in practice many complicating factors come in the way of evaluating the age.

Biology and Biochemistry:

Application of TL technique in the study of biological and biochemical systems is increasingly favoured in recent times and necessarily all the measurements are done in the LNT-RT range. The attempts have been successful in the study of hydroxy and aminobenzoic acids, proteins, nucleic acids, plant leaves, algae and bacteria. The TL results could indicate the proper stability of the or the orthoform of the benzoic acid, the inter and intra molecular transfer of radiation damage in nucleic acids, proteins and their constituents could be correlated with their TL behaviour; the photosynthetic electron transport routes in the Z diagram could be correlated with TL and additional routes delineated and the interaction between salts and proteins could be understood from the TL patterns.

Forensic science:

The major study in forensic sciences is to evolve and standardizes methods to compare evidentiary materials with similar materials of known origin, which are invariably available only in minute quantities and are required to be analyzed nondestructively for evidence purposes. Thermoluminescence can offer an attractive technique in selected materials that are commonly encountered in the criminal cases viz; glass, soil, safe insulation terials, etc . This can be used as an exclusionary evidence i.e. when the TL characteristics do not match it can be said with certainty that a particular sample has not come from a known source .To reduce the probability of any coincidental matching and improve the confidence of the TL measurements whose signal to noise ratio may be bad, examination may be made of the TL glow curves from the virgin samples as well as after a heavy artificial gamma or X-ray irradiation and also of the emission spectra.

Geology:

Geology is one of the earliest disciplines to accept the TL technique in its fold in a variety of applications, such as dating of mineralization, igneous activities, sedimentation and evaluation of growth rate of beaches and sand dunes.

The TL technique has been found useful in dating specimens of geologically recent origin where all other conventional methods fail. In a geological specimen, the TL would starts building up from the time of its crystallization and would normally continue throughout its existence due to the radioactivity present within the minerals and in the surrounding materials, till its saturates. If one selects a material with a negligible radioactivity in it (e.g. quartz) the accumulated TL mostly represents the environmental dose rate at a place from where the geological specimen was collected.

Accumulation of TL can be affected by natural light especially its ultraviolet component. In geology the sunlight bleaching is considered to be the basis for dating the geological event. The exposure of sand grains to sunlight during their weathering and transport through wind and water results in bleaching of their geological TL. This bleaching is effective enough to reduce thermoluminescence level to a negligible value. These bleached sand particles, once embedded in a sand dune or bleach, get shielded from further exposure to sunlight. This helps particles to acquire more TL due to radiations exposure from their new environment within the sand dune or on the seashore. At present using single grain technique age of geological samples can be estimated upto 50 million years with an accuracy of +5% or –5%.

Quality control in Industry:

As early as 1938, the application of TL in the control of feldspars in ceramic products has been described. The amount of TL given out by a ceramic after artificial irradiation is directly indicative of its feldspar contains at trace levels where any other type of quantitative analysis is time consuming. Thus in ceramic industry where a particular process is repeated many number of times to produce batches of the some materials, any controllable variations in the feldspar contents can be checked quickly and efficiently.

The efficiency of certain surface catalyst like Al_2O_3 can be quickly and efficiently evaluated by their TL sensitivities .The lattice defects which permit the adsorption reactions might also play a role in the TL emitted by these substances and the nature and intensity of TL may be gainfully correlated with the catalytic activity. The TL glow curve in such a cases could be used as criterion in controlling the preparative parameters of a desired catalyst. In principle, TL method could be employed in the quality control of many of the glass, ceramics and semiconductor products; recently it has been shown in the case of textile fibers that the low temperature TL glow curve changes can be correlated with the structure differences and / or chemical tracer impurities. However these have not yet received the attention of the industries.

Radiation Dosimetry:

In the present scientific world, ionizing radiations have been found very useful in engineering, medicine, science and technology. Professionals used them at every walk of life. In all the applications, the exact amount of absorption of radiation energy in the exposed material is important factor to get the desired results. The better use can be achieved mostly by accurate determination of energy absorbed from the radiation field and it possible the distribution of this absorbed energy within the material. Measurements of these quantities form the basis of radiation dosimetry and systems used for this purpose are referred as dosimeters. Professionals have worked in this direction, investigated and standardized many analytical methods to estimate the doses of radiations. The important techniques developed and employed are as under;

1. Fluorescence technique
2. Lyoluminescence method
3. Diffused reflectance technique.
4. Thermally stimulated luminescence technique [TLD]
5. Optically stimulated luminescence technique [OSL]
6. Electron paramagnetic resonance technique [EPR dosimetry]

The main basis in the Thermoluminescence Dosimetry (TLD) is that TL output is directly proportional to the radiation dose received by the phosphor and hence provides the means of estimating unknown irradiations. Also, TL can provide a perfect passive measurement i.e. integrated irradiation levels over extended periods of the order of even years. Thus, it finds immense use in the monitoring of doses received by radiation workers on a routine basis; weakly/ monthly /yearly depending upon whatever a situation many warrant. It should however be borne in mind that most of the TL phosphors are not tissue equivalent (in terms of energy absorption by irradiation) and hence the relevant dose which is medically significant to a radiation worker from protection point of view is not readily obtained. Some

of the phosphors like LiF, $Li_2B_4O_7$, BeO etc which are nearly tissue equivalent score 4 definite points over others like $CaSO_4$, CaF_2 Mg_2SiO_4 etc which are however more sensitive. Many phosphors have been developed for TLDs.

The application potential of TL-dosimeter is very high. They have been found very useful in many fields on account of several favorable characteristics such as high sensitivity, small size, ability to cover wide range of exposure / dose, reusability, insensitive to environmental conditions. In the past professionals had used the film budge technique in real practice. Later on they found that TLD technique is better for many reasons. And hence during last three to four decades they have developed and established the TLD technique. This is became popular now-a-days prominent applications of thermoluminescence dosimetry and radiation protection. The dosimeters have been widely used for in-phantom and in-vivo dosimetry, in medical applications. Another area, where thermoluminescence dosimeters have found use is personal monitoring of radiation workers.

On account of their ability to integrate over long periods of time and measure very low exposure, they have been widely employed for environmental monitoring of doses of the order of a few micro gray. The TLDs have been employed in protection monitoring for measurement such as leakage radiation levels on and around source containers, air scatter measurement around open top installations, area monitoring around radiation installations etc. Rapid fading ratio of main TL low temperature peal of certain phosphors such as CaSO4: Dy has been using for the estimation of time of exposure after irradiation.

It has been found that this technique can also detect and assess the thermal and fast neutron doses. Since TL phosphors insensitive to thermal neutrons are also available, combination of dosimeters can be employed for estimation of gamma and thermal neutron dose in mixed field. Besides this, TL dosimetry also include archaeological dating i.e. dating of ancient potteries and ceramics, space dosimetry, dosimetry of non-ionizing radiations such as UV and microwave dosimetry. If UV dosimeter has sensitivity close to the thermal response of the human skin, it would provide a measure of the thermally effective value of the UV energy. On the other hand TLDs can also find useful in agriculture. In this field they use mainly concerned with high level photon dosimetry such as dose measurement in food preservation, radiation sterilization of seed, pest control etc. Formally, the dose measurement in agriculture relied heavily on chemical dosimeters e.g. the ferric (Fe^{2+}, Fe^{3+}) system. TLDs constitute a less expensive method and are applicable in the dose range of 10^{-4} to 10^{8} rad.

Experimental

Alkali Halide:

The aim of this is to record and analyze the TL glow generated from the common salt NaCl after irradiating it with beta radiations for 5 minutes. The nature of the glow curve has already been well studied for most of the alkali halides but the trap parameters analysis of the same is not done.

Alkali halides are still the predominant subjects for study in the present – day luminescence research. Their lattices are cubic and many of their properties are profoundly affected by strong coulomb interaction which results from the highly ionic nature of these solids. Their large binding energies (200Kcal/mol) result in high melting point (1000 K), which offers a vast range of temperature over which phenomena may be studied. The large electronic band

gap (8eV) of these solids results in wide range of optical transparency and thus a very broad spectral region is available for the study of the effects of impurities vacancies and other crystalline defects. Attempts have been made to investigate the nature of the center responsible for the intrinsic luminescence of the alkali halide first of week and Teegarden showed that an emission identical with intrinsic luminescence can be stimulated by irradiation in the F & F' bands formed by exposure to ultraviolet light at 93K. This indicates that the luminescence is due to the recombination of electrons with trapped holes either by tunneling from an excited state of the electron trap or by electrons reaching the trapped hole via the conduction band. Presumable can be stimulated the electron is captured in an excited state about the trapped hole and luminescence occurs when the hole and electron recombine.

Many investigators in the past have observed a co-relation between the bleaching temperature of some absorption band and the temperature of the maxima of TL glow peaks in several alkali halides. This led them to conclude that TL studies correlated with measurement of optical thermal bleaching of colour centers.

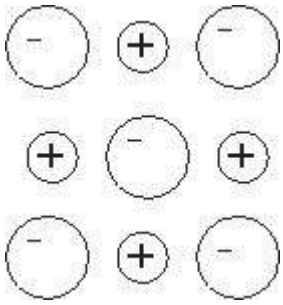
The thermoluminescence phenomenon was known since long but real interest in it started with the realization of its usefulness in radiation of its usefulness in radiation Dosimetry. The phenomenon of TL is closely related with colour center studies specially coloration due to irradiation with ionization radiation (X-ray ,-α ,- β,- γ radiation).

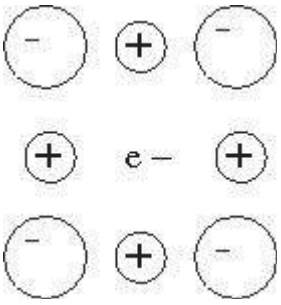
In this respect alkali halides have been studied extensively some work on TL of alkali halides other than LiF is also known but these phosphors did not find any place in radiation dosimetry, due to their low sensitivity. However, lot of study has gone into finalization the nature of the trap and various workers have come out with different models. Knowledge of the nature of traps is useful for the understanding of the TL process. In what follows the TL processes in alkali halide as reported in literature are presented in brief.

TL is comparatively weak in pure alkali halides. The study of F-center formation in this phosphor has shown presence of two stages. The first stage is suggested to be due to the trapping of electrons at already existing negative ion vacancy in crystal. The second stage of F-center formation is attributed to the creating and filling of negative ion vacancies during irradiation with ionizing radiation. Correlated studies between F-center and the TL peaks in various alkali halides have shown clearly that two different peaks are associated with two stages of F-centre formation.

The hole trapping is normally explain to be due to interstitial. The trapped holes are released in the TL reading processes, which combine with electrons at the F-center sites giving rise to emission. A simple Model for NaCl is shown below.

The simplest example is NaCl. A pure sample of NaCl will look like this (right). Here, the lattice takes on a regular, repeating shape.





After irradiation with x-rays, gamma rays, or beta radiation, the resulting crystal will look like this (left). Some of the anions have fallen out of the lattice, and single electrons have taken their place. The electron trapped at such negative ion vacancies are called F-Centers.

METHODS FOR EVALUATING PARAMETERS FROM THERMALLY STIMULATED GLOW CURVE

In the majority of cases a number of peaks are observed during the heating of the sample in a certain temperature range in more favourable cases the overlapping is minimum so we can treat as individual peak. In some of thermally stimulated phenomena the kinetics of the process is usually simple being of first order, second order or general order .Once one is satisfied that the peak under investigation is of such a simple nature , the evolution involved only of three parameters – the activation energy , the pre exponential factor and the order of kinetics.

Many of the methods discussed in the present chapter were developed for the simple particular cases of two or three parameters dependent single TL peak. Some of these can quite easily be adapted, to peaks of the other thermally stimulated processes.
Values of the parameters, which seem to be most important to the investigator, are:

1. **E- Activation energy**
2. **s- The frequency factor**
3. **b- Order of kinetics**

It is expected that these parameters are independent of each other and of concentration parameters. This means that one hopes, for example, that for a particular electron trap, the activation energy, the attempt to escape frequency factor and the retrapping probability are not dependent on the concentration of the trap. Most of these methods were developed for the evaluation of the activation energy which, therefore in many cases, be calculated by a number of methods witch thus provide a cross check on the results. In the following section we will discuss the various methods developed for the evaluation of trapping parameters.

In a rough way, one can divide the methods for evaluating parameters by peaks of thermally stimulated phenomena into the following groups:

- Heuristic methods: Methods developed mainly in the early stages of investigation of thermally stimulated curves based on empirical ground or otherwise unproved methods which turned out to be useful for certain cases.

- The initial rise method: This method is used particularly all the thermally stimulated phenomena for evaluating the activation energy.

- Curve fitting methods: This method based on many measured points in a broad temperature range. The initial rise method is, in away, special case but due to its extensive use it can be taken as a separate group.

- Peak shape methods: It is based on the maximum temperature and two half intensity temperature or, alternately, on the two inflexion points.

- Various heating rate methods

- Isothermal decay methods

➢ HEURISTIC METHOD

The methods included in the present section should be considered as being mainly of historical values or as first approximation for the evaluation of activation energy. Although admittedly, the use of other methods usually involves approximations as well, the accuracy expected in this method is generally poor. Assuming that in a given sample, the frequency factor is more or less the same for different peaks, one would expect that the bigger the activation energy the higher the maximum of the peak. The equation given by Urbach is:

$E\ (eV) = T_m(K)/500$ ----------1

This can be written as in the form of Eq(2):

$E\ (eV) = 23kT_m$ ----------2

And for the special case i.e. for NaCl it is the Eq(3):

$E\ (eV) = 38kT_m$ ----------3

➢ VARIOUS HEATING RATE METHODS

A number of related methods, all based on the repeated measurement, of a certain peak at different heating rates and keeping all other parameter equal, have been independently developed in the research of practically all the thermally stimulated phenomena. These methods can be most easily introduced by studying the equation for the maximum of first order peak can be written as in Eq(4):

$$\beta = \frac{s}{E} T_m^2 \exp\left(-\frac{E}{kT_m}\right) \quad \text{----------(4)}$$

➢ PEAK SHAPE METHODS

This method is based on a small number of points along the curve have been developed mainly in investigation of thermoluminescence. This however can very easily be applied to other thermally stimulated process also. The points used are in most cases the maximum temperature $\mathbf{T_m}$, the half intensity temperature at low and high part of the peak $\mathbf{T_1}$ & $\mathbf{T_2}$ respectively and are shown in figure-1.3. In small number of cases two inflexion points are utilized rather than half intensity ones. Lushchik (1956) developed methods for evaluation of E by using the high temperature half width of the peak.

GLOW CURVE SHAPE

The glow curve shape methods extract information from the glow peak by utilizing the peak temperature T_m and two temperatures T_1 and T_2 on either side of Tm corresponding to half peak intensity at the low and high temperature sides of the peak as well as half width parameters and the symmetry properties.

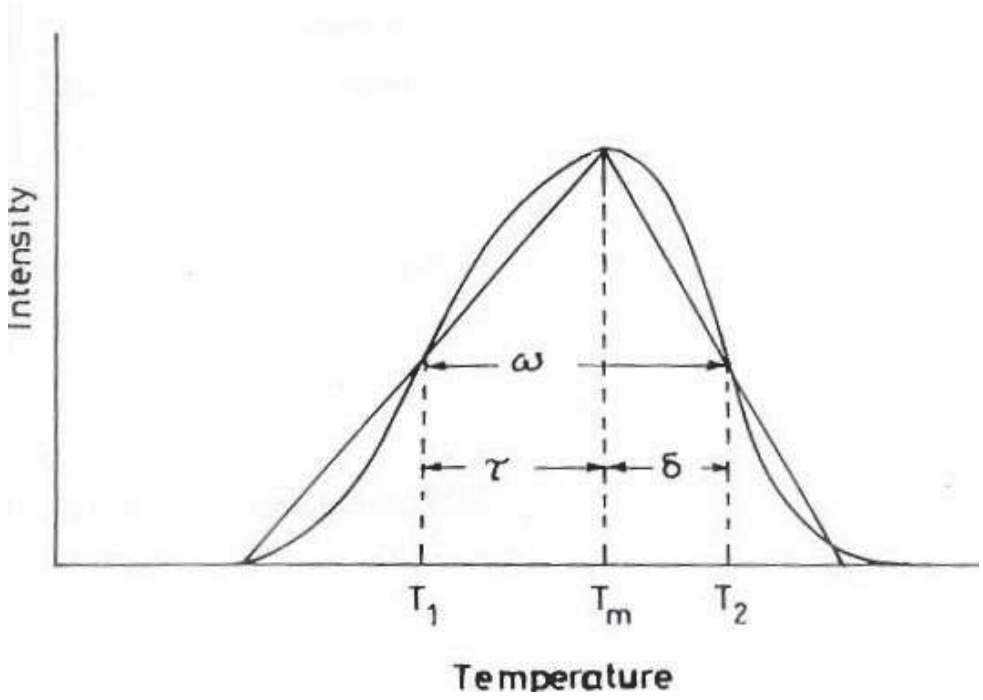


Fig.4

The equation is given by

$$E = 2kT_m^2/\delta \qquad \text{----------(5)}$$

Chen (1969) questioned the "triangle assumption" and tested its validity for a wide range of activation energies and pre-exponential factors for both first and second order peak. Instead of the Lushchik assumption which can be written as:

$$\delta I_m/ßn_m = c_\delta \qquad \text{----------(6)}$$

Chen has also given Eq(7) below, which is summation of all the equations and it was found to be the most appropriate in calculating the Activation energy**.**

$$E_\alpha = c_\alpha\left(kT_m^2/\alpha\right) - b_\alpha 2kT_m \qquad \text{----------(7)}$$

Where α stands for δ, ω or τ. The values of c_α and b_α for the three methods and for first and second order are shown in the table-1.

First order				Second order		
	τ	δ	ω	τ	δ	ω
C_α	1.51	0.976	2.52	1.81	1.71	3.54
b_α	1.58+a/2	a/2	1+a/2	2+a/2	a/2	1+a/2

Table-1: Coefficients appearing in equation for the various methods of calculating activation energies (where a in the table is the power of the temperature dependence of the pre-exponential factor).

Regarding the distinction between first and second order peak, as Halperin & Braner suggested to use the "symmetric factor" μ_g=δ/ω. As further discussed by Chen, a first order peak is characterized by μ_g =0.42 and a second order one by μ_g=0.52, when μ_g is only slightly dependent on the particular activation energy and pre-exponential factor involved. A slightly different treatment of the same measured quantities has been suggested by Balarian. He also suggested the use of the symmetry of the peak to distinguish between first and second order peaks but preferred to check the value of δ/τ., which should be 0.7 to 0.8 for first order and 1.05 to 1.2 for second order kinetics. Chen has also suggested a method for finding c_α and b_α in Eq (7) for the non first & second order cases by the use of the known values of μ_g = 0.42 for first order and μ_g=. 0.52 for second order, and measure the μ_g as an interpolation parameter. The equations for this general case are still with the coefficient being:

$$c_\tau = 1.51 + 3(\mu_g - 0.42) \text{----------(A)}$$

$$c_\delta = 0.976 + 7.3(\mu_g - 0.42) \text{----------(B)}$$

$$c_\omega = 2.52 + 10.2(\mu_g - 0.42) \text{----------(C)}$$

$$b_\tau = 1.58 + 4.2(\mu_g - 0.42) + \frac{a}{2} \text{-------(D)}$$

$$b_\delta = \frac{a}{2} \text{----------(E)}$$

$$b_w = 1 + \frac{a}{2} \text{ ----------(F)}$$

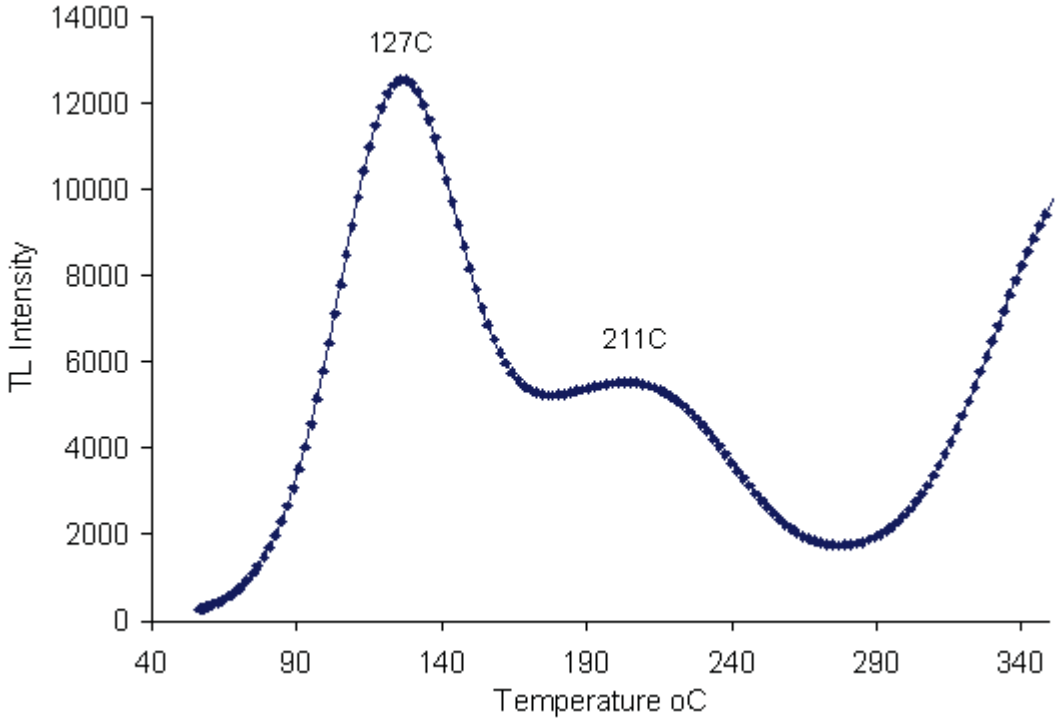


Figure 5: TL glow curve for the beta irradiated NaCl

Analysis of Glow Peaks:

The glow curve for the beta irradiated sample for NaCl is shown in figure-5. The glow curve shows well-resolved glow peaks around 127^{o}C and another at 211^{o}C. The TL was recorded by keeping the heating rate at 2^{o}C/sec. The analysis of any TL glow curve i.e. the analysis of trap parameters by various methods and to see what kind and nature of traps are there, is an important tool to know about the nature of the material. The analysis of the same can be done from the various methods that are described as below and the analysis of the study was done on the same. The activation energy, the frequency factor, and the shape alone i.e. the order of kinetics can dwell so much of information to the nature and the type of the glow processes taking place in the specimen and one can conclude the mechanism for it too. The study had been extensively done by Chen et. al. and Mckeever et. al. and is still carried out till today, as the model proposed for the same are of interest to the physicists. The values for the beta irradiated NaCl peak has been tabulated in table-2. It can be seen from the evaluated results that for the different equations as proposed by different scientists, different values were obtained for all the methods. The oldest one which was proposed by Urbach is the easiest as it require only the peak temperature T_m of the glow curve. The activation energy calculated by various methods vary from 0.65 to 0.76eV for peak -1 but the equation given by Halperin et al , specially for NaCl, gives the value as 1.25 eV. For Peak-2 the activation energy was found to be varying from as low as 0.39 to 1.6 eV, the values calculated for activation energy

by Chen's equation are considerably very low compared to all the other equations. We feel that this fluctuations in the activation energy for the Chen's equation for peak 2 are due to the experimental errors or overlapping of many peaks. We found out that all the other methods except the Chen are very approximate so one has to consider the values coming from the Chen's equation as correct.

The frequency factor was calculated by Randall & Wilkins equation i.e.

$$E = k\, T_m \ln s. \text{ ----------(8)}$$

The frequency factor, s, has also been calculated for Peak -1 and Peak-2 and are tabulated in Table - 1. It was found that the frequency factor for Peak -1 varied from 3.93×10^8 to 3.12×10^{16} / sec. But as there was variation in activation energy for Peak-2 due to that it was found that there was also drastic variation for the frequency factor of Peak -2. The reasons for the variations were the same as stated above.

TL characteristics of beta irradiated NaCl give rise to interesting results like generation of two well resolved peaks at 381 and 498K. The trapping parameters namely, activation energy, frequency factor was calculated using various methods available. It was found that the Peak-1 at 381.58 K by the Chen's equation was most appropriate. Whereas for the peak-2 there was a drastic variation of E and s values. Since the commercial NaCl consists of many impurities which leads to mixed TL peaks and generation of the many types of traps. However the values calculated using the equation $E(eV) = 38kT_m$ are simply doubled which may be due to approximation done by the Urbach.

Table-1: Tabulated form of the activation energy and the corresponding frequency factor as calculated form the various equations given in the text.

S. No.	Equations	For Peak 1 Tm = 381.58 K		For Peak 2 Tm = 498.7 K	
		Energy (eV)	Frequency Factor (sec^{-1})	Energy (eV)	Frequency Factor (sec^{-1})
1.	$E(eV) = T_m(K)/500$	0.763	1.17×10^{10}	0.9974	1.18×10^{10}
2.	$E(eV) = 23kT_m$	0.7569	0.97×10^{10}	0.9892	0.98×10^{10}
3.	$E(eV) = 38kT_m$	1.250	3.12×10^{16}	1.634	3.16×10^{16}
4.	$E = 2kT_m^2/\delta$	0.6520	4.01×10^8	1.479	8.66×10^{14}
5.	$E_\omega = c_\omega\left(kT_m^2/\omega\right) - b_\omega\, 2kT_m$	0.657	4.68×10^8	0.4224	1.8×10^4
6.	$E_\tau = c_\tau\left(kT_m^2/\tau\right) - b_\tau\, 2kT_m$	0.6636	5.72×10^8	0.44	2.77×10^4

7.	$E_\delta = c_\delta\left(kT_m^{\,2}/\delta\right) - b_\delta\,2kT_m$	0.6513	$3.93 * 10^8$	0.397	$1.0 * 10^4$

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Application of TLD systems for personnel monitoring

CHAPTER - II

Application of TLD systems for personnel monitoring

INTRODUCTION:

Personnel monitoring is based on the international recommendations of the ICRP. The primary objective of individual monitoring for external radiation is to assess, and thus limit, radiation doses to individual workers. Supplementary objectives are to provide information about the trends of these doses and about the conditions in places of work and to give information in the event of accidental exposure [1]. Depending on the kind of radiation hazard, the ICRP recommend maximum permissible dose (MPD) values. These are the maximum dose equivalent values, which are not expected to cause appreciable body injury to a person during his lifetime. With respect to the various MPD values, the following quantities should be measured in personnel monitoring:

a. Skin dose or the surface absorbed dose to assess the dose equivalent to the basal layer of the epidermis at a depth of 5-10 mg cm^{-2}, if only non-penetrating radiation has to be considered (x-rays<15 keV, γ-rays);
b. Whole body dose or the equivalent at a depth of 400-1000 mg cm^{-2} below the surface of the body to assess or over-estimate the effective dose equivalent or the average dose equivalent in the critical organs for the case of penetrating radiation and whole body irradiation (x-rays>15 keV, γ-rays, neutrons);
c. Extremity dose to assess the maximum value of the dose equivalent (skin dose) in tissue to any part of the hands, forearms, feet or ankles.

In contrast to film dosimetry, approximately tissue-equivalent TL detectors of small size and high precision in measurement are available which may serve as an ideal extremity dosimeter and as a basic dosimeter for the dose estimation of photons in the energy range of interest as well as for the detection of γ-rays and neutrons. In addition, a multi-detector badge offers practical possibilities for short-term and long-term monitoring periods, for separate indication of skin dose and body dose and finally for the estimation of radiation quality.

The role of TLD for an individual monitoring service is based on the following features:

a. TL phosphors are available in solid form as chips, extruded ribbons or in a Teflon matrix; the dose reading of some materials is approximately tissue-equivalent and largely independent of the angle of radiation incidence;
b. The dose reading is practically independent of dose rate up to 10^{11} rad s^{-1} and proportional to the dose up to several hundred rem;
c. In some TL materials the fading at room temperature is so small, especially after a post-irradiation annealing, that they can be used for issue periods of up to 1yr;
d. TL detectors are convenient to wear, suitable for postal service, flexible in issue period, can be evaluated in less than 1min and can be re-used, although a regeneration procedure prior to re-use is often necessary;

e. TLD lends itself to automation; with an on-line computer the calibration factor for individual dosimeters can be stored and also the shape of the glow curve may be checked to verify the radiation-induced TL.
f. For the reassessment of the dose recorded, a redundant detector can be included in the badge design.

TLD, the most advanced and most intensively studied integrating dosimeter system, has now reached the stage at which it may replace or supplement film dosimetry. Primarily for applications in personnel monitoring, various suppliers offer a number of commercial TLD systems with manual or automatic evaluation systems.

Application of TLD systems for environmental monitoring

A significant aspect of environmental monitoring is the limitation of radiation exposure values in man from the nuclear power fuel cycle. In the case of gaseous radionuclides released to the environment from a nuclear installation, the acceptable limit of exposure is based on an annual dose equivalent of 30 mrem, a value about a third that from natural terrestrial and cosmic radiation. An increasing amount of public interest in environmental monitoring programmes is being focused on the environmental impact of radiation arising from nuclear power operations and the corresponding detection of slight variations in the natural radiation background.

TLD systems are widely applied to environmental monitoring programmes near nuclear installations. TLD systems with high reproducibility in the milliroentgen dose range are required in order to measure exposures equal to that resulting from an exposure rate of 10μR h^{-1} during field periods of from several days up to a year.

For the application of TLD systems in environmental monitoring, therefore, special performance criteria and techniques for selecting, testing, calibrating and using a TLD system have been established:

a. The ANSI N545-1975 standard [1] specifies the minimum acceptable performance of TLD and outlines test methods for compliance. To meet these requirements, each laboratory has to carry out tests for determining their own limits of error.
b. On the basis of a standard test programme [41] and an inter-laboratory comparison, the performance and quality of a broad spectrum of TLD systems can be compared with respect to variations in the properties of reader, TL material, read-out method and annealing technique adopted in the laboratories.
c. Annual control exposures as well as inter-comparison experiments organized by the ERDA serve as a valuable way to compare one's own results with the international level [3].

This chapter reviews the properties of TLD systems and the common techniques used in the application of TLD in environmental monitoring, taking into account the results of a test programme and recent investigations of the long-term fading as well as the calibration technique and the interpretation of experimental results.

PERFORMANCE SPECIFICATIONS:

In contrast to the application in personal monitoring, TLD systems for environmental monitoring have to fulfill high requirements, such as

a. Good precision and reproducibility of measurement over the exposure range of interest (10-100 mrem);
b. Low fading over the field exposure period (3-12 months);
c. Insensitivity to environmental parameters, i.e. temperature, moisture, humidity, light;
d. Approximate tissue equivalence in dose reading;
e. Low self irradiation due to natural radio nuclides in the TLD phosphor or holder;
f. Encapsulation in a plastic holder to provide secondary electronic equilibrium, shielding against â-rays and light as well as water tightness;
g. Calibration techniques for each field cycle to guarantee the highest precision for the conversion to exposure and to correct for fading, transit exposure and zero-dose reading.

APPLICATION OF TLD IN MEDICINE:

There are two important areas of absorbed dose measurement in medicine:

i. Absorbed dose measurement in radiotherapy, and
ii. Absorbed dose measurement in diagnostic radiology.

RADIOTHERAPY MEASUREMENTS:

The difficulties of accurately predicting absorbed doses in radiotherapy by calculation have in the past led to the development of in vivo measurement techniques. While entrance and exit absorbed doses could be measured using films and conventional ionization chambers, intracavitary measurements were limited by the minimum size of available ionization chambers (typically 20mm x 5mm diam).

When Daniels first developed thermo luminescence as a practical method of assessing ionizing radiation exposure, it was realized that the technique could be applied in the field of clinical measurement. Brucer used some of Daniel's single crystals of Harshaw LiF to make internal in vivo measurements in cancer patients injected with radioactive material.

The arrangement of radiotherapy treatment fields is conventionally carried out using a combination of calculations involving standardized geometries together with depth dose and transverse dose measurements in phantoms. The final check on the absorbed dose delivered to the patient can be carried out by in vivo dosimetry. Similarly, absorbed doses to organs not involved in the treatment, which should be kept to the minimum, can be measured.

Thermo luminescence dosimetry has proved a useful technique for a variety of purposes in radiotherapy, including measurements of therapy machine output, beam uniformity checks and the measurement of absorbed dose in phantoms and in vivo for both internally and externally applied fields. Thermo luminescent dosimeters have a high precision, provide rapid retrieval of information (using on-site readers), have good environmental stability, have good water or tissue equivalence and have a wide range of sensitivities. The last characteristic is particularly important for in vivo measurements of absorbed dose. Because

of their small size, thermo luminescent dosimeters also give good special resolution. This is of particular value in many radiotherapy techniques where the absorbed dose has a rapid special variation. Thermo luminescent dosimeters may also be used to measure the absorbed dose to experimental animals.

DIAGNOSTIC RADIOLOGY MEASUREMENTS:

The collective dose from medical exposure has been estimated to represent the largest single man-made contribution to both the somatic and the genetically significant dose equivalent to the population of the United Kingdom as illustrated in figure representing some 31% of the total somatic dose and 9% of the total genetic dose, and 95% and 85% respectively of the man-made contribution. In other developed countries, the estimated figures are similar. By far the largest contribution is from diagnostic radiology, estimated as 10 times the sum of the contributions from nuclear medicine and radiotherapy.

New radio diagnostic techniques have been introduced, some involving the use of complex machines such as the head and body scanners (computerized axial tomography, CAT). Thermo luminescence dosimetry has proved to be a useful method in the comparison of patient absorbed dose from these new techniques as well as from the more traditional ones.

Diagnostic absorbed dose measurements are important for:

i. Improving the design of equipment to reduce patient absorbed dose, and
ii. Improving radiographers' techniques in the use of equipment to reduce patient absorbed dose, and for providing a measurement database for epidemiological analysis of population radiation absorbed dose from diagnostic radiology.

Thermo luminescent phosphors such as LiF: Mg, Ti and particularly the more tissue equivalent $Li_2B_4O_7$: Mn have been used for such measurements. Thermo luminescent dosimeters have three main advantages over ionization chambers for this type of measurement:

a. They are small and unobtrusive,
b. They are radio-transparent to most x-radiation, and
c. They do not require connecting leads and are easily attached to the patient.

FACTORS IN THE CHOICE OF DOSIMETERS FOR CLINICAL USE:

A number of factors have to be considered in the choice of the material and form of the dosimeters for clinical dosimetry. The most important factors are:

i. Estimated absorbed dose range of the intended measurements,
ii. Estimated equivalent photon energy or linear energy transfer (LET) of the radiation,
iii. Immediate environmental conditions around the dosimeter, and spatial resolution.

ABSORBED DOSE RANGE:

The sensitivity of any thermo luminescent dosimeter is proportional to the mass of active phosphor present, within limits imposed by geometrical and thermal considerations relevant to the readout system. Dosimeters, which contain only thermo luminescent material, e.g. powder, extruded ribbons and rods, have a much higher sensitivity than dosimeters consisting of a phosphor held in a matrix of binder material, e.g. PTFE-based discs, tape and micro-rods.

The range of absorbed doses encountered in clinical and biological irradiations is very large. In diagnostic radiology, absorbed doses may range from less than 10 μGy to 100 mGy to the gonads and from approximately 100 μGy to about 100 mGy to the skin. Hence, at the lower end of the diagnostic radiology range, there is a need for a sensitive form of dosimeter, e.g. powder or extruded forms. However, in therapy dosimetry, a single treatment fraction of absorbed dose may be several grays, and, in many animal or cell irradiations, tens of grays may be required. Less-sensitive forms of dosimeter can be used, especially those incorporating the phosphor powder in PTFE as discs, tape and micro-rods. The measurement of high-absorbed doses will often necessitate using the dosimeter above the linear thermoluminescence absorbed dose response region. Under these conditions, the degree of supralinearity needs to be determined. Often, in radiotherapy, simultaneous measurements of absorbed dose in the treatment region and the much smaller absorbed dose in the shadow of shielding may be required. In such cases, two types of dosimeter, such as extruded rods and PTFE-based rods, may be used in parallel. This particular combination of dosimeters, if appropriately oriented with respect to the absorbed dose gradient, should provide good spatial resolution.

PHOTON ENERGY RANGE AND LET OF RADIATION:

Modern routine radiotherapy and radio diagnostic techniques use a wide range of photon energies from conventional x-ray machines of approximately 10 keV to200 keV, from ^{137}Cs (0.67 MeV) and ^{60}Co (1.25 MeV) teletherapy units and from accelerators producing high-energy electrons and mega voltage photons.

The total light emitted by an irradiated phosphor is proportional to the total radiation energy absorbed by it. In tissue, the absorption of Compton-scattered electrons is the most important absorption process in the photon energy range from approximately 20keV to 10 MeV. For elements such as lithium, boron, oxygen, fluorine, etc, of low atomic number, and for photon energies up to about 15 keV, the photoelectric effect is dominant. Thereafter, up to 10 MeV, Compton scattering is most important. For elements of high atomic number, such as those used as dopants (e.g. Li, Mg, Mn, etc), the photoelectric effect is dominant up to several hundred kilo electron volts.

The advantage of using materials consisting mainly of atoms of low atomic number with only a few dopant atoms of higher atomic number is obvious because of their good approximation to tissue and air. This is particularly true of phosphors based on lithium borate.

In order to evaluate the absorbed dose to a phantom or patient using thermo luminescent dosimeters, it is essential to know the relative energy responses of the dosimeters throughout

the range of energies used. The primary response calibration of dosimeters is usually carried out using a ^{60}Co source (1.25 MeV) and the responses at all other energies and for all other radiations are expressed as multiples or fractions of this. For clinical applications, the response is most usefully expressed as the light emitted per unit-absorbed dose in tissue or water. This will be a function of radiation energy and of the physical form of the dosimeter.

The beam quality has to be known. Photon-beam quality determination, although in principle relatively straightforward to determine in free air, is difficult to determine uniquely in water or solid phantoms because of two effects:

i. The contribution from lower-energy scattered radiation from the phantom and external shielding material, e.g. the applicator cone at short focus-to-skin distances (also at low photon energies the effects of dosimeter orientation and self-shielding become increasingly important), and
ii. The effective 'hardening' of the beam with increasing depth in the water or solid phantom.

The thermo luminescence absorbed dose (water and polystyrene) response of LiF: Mg, Ti to high-energy radiations, of which those of principal interest in clinical applications are mega voltage photons and high-energy electrons, has been widely investigated and reported in the literature. The results have often been inconsistent. Some investigators have measured approximately 10% reduction in response to high-energy radiations compared with that to ^{60}Co gamma radiation, and others have not found any reduction. Much discussion has revolved around the application of various generalized cavity theories to attempt to explain the observed effects and to reconcile the differences.

ENVIRONMENTAL FACTORS:

Absorbed dose range and radiation energy considerations apart, environmental factors such as temperature, humidity, contact with body fluids, insertion into catheters, sterilization, etc, influence the choice of dosimeter form and packaging. If dosimeters are not protected from their environment, the result is often low precision and sometimes gross error in absorbed dose measurement.

TEMPERATURE AND HUMIDITY:

During exposure under clinical conditions, dosimeters may come into contact with heat (human body core temperature is 37^{O}C) and/or high-humidity environments. If implanted or introduced into body cavities, they can come into contact with body fluids. Some phosphors (especially in powder form) have been shown [14] to be affected by humidity as well as by storage at elevated temperatures, which induces fading.

OTHER AGENTS:

If dosimeters in solid form are attached directly on to the skin using adhesive tape, care should be taken to remove all traces of adhesive from the dosimeters before readout. Adhesives often exhibit thermo luminescence following exposure to visible light and/or ultraviolet radiation. The simplest way of avoiding these effects is to seal the dosimeters inside protective envelopes (e.g. polythene).

STERILIZING OF DOSIMETERS:

Occasionally, a clinician or biologist will require dosimeters to be sterilized. The three common methods of sterilizing. i.e. autoclaving, chemical sterilizing and irradiation with 254 nm ultraviolet radiation, can all have a gross effect on the inherent sensitivity of the dosimeter or may induce spurious luminescence. In general, provided the phosphor is effectively sealed in a protective envelope or catheter, which is opaque to the sterilizing ultraviolet radiation, either chemical or ultraviolet sterilizing at normal ambient temperature is recommended. Normal ambient temperature is emphasized, as the effects of elevated temperatures on the normal sensitivity of phosphors, especially LiF: Mg, Ti, can be significant. The effects of autoclaving can be particularly severe.

SPATIAL RESOLUTION:

Good Spatial resolution of absorbed dose measurement is generally useful, and is essential in the determination of high-absorbed dose gradients. Thermo luminescent dosimeters are available in many shapes. Powder acts like a fluid and will adopt the shape of its container. The micro-rod and extruded ribbon (and hot pressed) dosimeters are so small, 1 X 1 X 6 mm^3 and 3.2 X 3.2 X 0.9 mm^3, respectively, that the effective size of the dosimeter is often limited in practice by the requirement to have adequate build-up to ensure electronic equilibrium.

RADIOTHERAPY ABSORBED DOSE MEASUREMENTS

SIMPLE GEOMETRY PHANTOMS:

In radiotherapy, the specification of the complete absorbed dose distribution within the radiation beam in a phantom is a prerequisite to ensuring that the prescribed absorbed dose is delivered to the target volume in the patient. A common method is to employ published depth dose data and an isodose chart. An example of such a chart is illustrated in figure. This chart refers to a section containing the beam axis parallel to one side of a ^{60}Co 10 X 10 cm^2 therapy beam for a fixed source-to-skin distance (SSD) of 80cm. The lines mapped on the chart link points of equal absorbed dose expressed as a percentage of a peak absorbed dose. In the case of ^{60}Co radiation, the peak-absorbed dose occurs at the optimum 'build-up depth' in water, 5 mm. For x-ray beams produced with generating potentials of less than 400kV, the depth doses are conventionally expressed as a percentage of the surface absorbed dose. Similar charts are used for fixed source-axis distance (SAD) beams. However, in these, the isodose values are expressed as a percentage of the absorbed dose at the target deep within the phantom. SAD isodose charts are used when the target volume is located on the axis of rotation of the tele-therapy machine. The selection of an appropriate isodose chart can be difficult, as the absorbed dose distribution in the phantom depends on the beam dimensions, SSD or SAD, the radiation quality, the source size, the geometry of the beam and the positioning of the beam collimators. The International Commission on Radiological Units (ICRU) [15] therefore recommends the use of isodose charts, which are exactly specified for the particular equipment being used. This criterion can be established, as ICRU recommend, by a series of single measurements using an ion chamber or thermo luminescent dosimeters.

In their simplest form, the measurements consists of:

a. Measuring the depth dose distribution along the central axis of the beam in a water or water-equivalent phantom, and
b. Choosing one particular phantom depth (which in the case of 150 keV to 10 MeV and ^{137}Cs and ^{60}Co teletherapy beams, ICRU recommends as 5 cm) and measuring the radiation absorbed dose profile across the beam at this depth.

After normalization of the depth dose measurements at 5cm depth, the published dose data which one intends to use can be compared with them and corrected accordingly. Similarly, the measured beam profile can be compared with that obtained from the published isodose chart.

Since 1968, the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) have been running a programme of inter comparison of ^{60}Co teletherapy units in the various radiotherapy centers throughout the world. This resulted from investigations carried out in 1965 which revealed that there was no suitably calibrated radiation measuring instrument in use in about 30% of the radiotherapy centers investigated [16]. A simple test procedure based on thermo luminescence dosimetry is used to assess the accuracy of delivered absorbed doses in the centers.

LiF: Mg, Ti power dosimeters contained in PTFE capsules are sent to radiotherapy centers. The measurement technique used in this study illustrates:

i. The practical use of thermo luminescent dosimeters for radiotherapy depth dose measurements in a simple phantom, and
ii. Methods to eliminate effects of fading and other variable environmental factors.

The procedure used is illustrated in figure

Participant centers are sent four sets of dosimeters. They are requested to irradiate one test set (A) with an absorbed dose of 2 Gy in water at 5 cm depth on the central axis of a ^{60}Co 10 X 10 cm^2 therapy beam with an 80 cm SSD. Another test set (B) is to be irradiated under similar conditions for 2min. A control set (C) which has been given a known absorbed dose by IAEA and a control set (D) which is unexposed accompany sets A and B at all times except during irradiation. Sets C and D provide information about any environmental or spurious effects, such as thermal fading, unintentional irradiation, etc, which might adversely affect the test dosimeters. In addition, reference sets (R) are irradiated by IAEA in a standardized 10 X10 cm^2 ^{60}Co beam (SSD 80cm) at a depth of 5cm in water. The absorbed dose rate expressed in grays per minute in water is obtained from a measurement of the exposure rate in free air using a calibrated ionization chamber. All dosimeters are then read out together, eliminating possible calibration errors due to fading and effectively standardizing the readout procedure for all dosimeters.

B. IN VIVO MEASUREMENTS

While the measurement of complete absorbed dose distribution in a phantom is essential in planning the treatment of a patient, the ultimate check on the absorbed dose delivered to the patient can only be made by in vivo absorbed dose measurements. Thermo luminescent dosimeters have proved to be particularly useful for this purpose.

The relevance of in vivo dosimetry is illustrated by the flowchart shown in figure. This flowchart is a simplified form of that used by ICRU [15] to illustrate a systems approach to radiotherapy. In vivo measurements verify that the absorbed dose prescribed by the clinician, and calculated and set up by the physicist and the radiographer, has been delivered. Further, it may be used to monitor any change in field uniformity caused by changes in the many treatment parameters.

In vivo measurements can be divided into four classes.

Class 1 – entrance absorbed dose measurements. These are used mainly to check the machine output, the absorbed dose distribution profile across the patient, particularly in the penumbra of shielding, and the positioning of shielding in relation to the patient. If the measured values are at variance with those prescribed and calculated, the cause can be investigated and appropriate corrective action taken. The spatial resolution afforded by thermo luminescent dosimeters is particularly useful in these measurements.

Class 2 – exit absorbed dose measurements. These are used mainly to check the absorbed dose delivered to points deep within the body. The measurements should agree with calculations for exit-absorbed doses. For such measurements, the dosimeters should be provided with sufficient backscatter material. Again, good spatial resolution may be important.

Class 3 – intracavitary absorbed dose measurements. The absorbed dose within a body cavity, e.g. the mouth, nasopharynx, oesophagus, vagina, rectum, etc, can be measured using dosimeters sealed inside a catheter as shown in figure. The position of the dosimeters may be checked using radio-opaque markers and exposing an x-ray film. The increase in scattered radiation resulting from the presence of radio-opaque markers of high atomic number can cause uncertainties of a few percent in the absorbed dose to the dosimeter. This can be measured and allowed for.

Class 4 – individual spared organ absorbed dose measurements. The absorbed dose to spared (shielded) organs can be measured, but often no build-up can be used as this would in itself result in an increased adsorbed dose to the organ.

EXAMPLES OF THE USE OF TL DOSIMETERS IN RADIOTHERAPY

Thermo luminescent dosimeters are routinely used for a number of different types of in vivo radiotherapy measurements in centers throughout the world. The following examples illustrate some of the principles of their use.

A. MEASUREMENT OF ABSORBED DOSE DURING 'MANTLE THERAPY' FOR HODGKIN'S DISEASE

The radiotherapy treatment of Hodgkin's disease involves the irradiation of a large area of the body. The treatment field is designed to deliver a therapeutic or prophylactic absorbed dose to the axillary, cervical and mediastinal lymph nodes. Many different treatment fields have been used, but one commonly used configuration consists of anterior and posterior parallel and opposed fields as illustrated in figure. There is also the need to shield presumed healthy organs, e.g. lips, eyes, lungs, kidneys, bone joints, etc, and for posterior irradiation the spinal cord needs to be shielded. To avoid excessive exposure of the skin (skin sparing), the treatment is carried out using either ^{60}Co or mega voltage x-ray photons and the shielding is positioned some distance (typically 20 to 50 cm) above the entrance surface of the body. This is achieved using 'individually tailored' moulds of polystyrene, one anterior and one posterior, with appropriately cut out channels containing lead-shot shielding. Alternately, appropriately shaped lead absorbers, placed on a Perspex plate and positioned above the body, have been used. The technique is termed the 'Gothic arch' or 'mantle' technique. A typical four-week course of treatment involves a total prescribed absorbed dose of between 30 and 40 Gy delivered in 20 fractions.

Thermo luminescent dosimeters, usually LiF extruded ribbons or rods or PTFE-based discs or micro-rods sealed in thin protective polythene sachets, are attached to the body under moulded blocks of wax or in small Perspex containers. The dimensions of the wax or Perspex are chosen to provide build-up appropriate to the photon energy of the beam and to ensure electronic equilibrium. With the use of high-energy photon radiation, e.g. 42MV x-rays, Ruden [10] recommends the use of a maximum build-up of 15mm Perspex and an experimentally derived factor to correct the apparent absorbed dose.

B. INTRACAVITARY ABSORBED DOSE MEASUREMENT:

The small size and shape of the extruded and PTFE-based micro-rod dosimeters have enabled in vivo measurements of absorbed dose inside body cavities, which hitherto were often difficult and sometimes impossible. As illustrated in figure, these dosimeters can easily be inserted and sealed in catheters.

A very good example of such applications is the in vivo measurement of absorbed dose distribution in the pelvis during intracavitary ^{226}Ra and external beam therapy for carcinoma of the uterine cervix [17-19].

The dosimeters are introduced into the pelvis via the external femoral veins. In one technique [17], sterile PTFE catheters are first inserted in the veins. This process can be monitored using x-ray fluoroscopy and television. Inner tubes containing gold radio-opaque markers are then introduced into the catheter to assess accurately the intended positions of the TL dosimeters. The radium is then applied and its position in relation to the dosimeter markers can be assessed. The marker catheter tubes are then removed and replaced by two others, each containing 15 micro-rod dosimeters spaced some 16 mm apart. Using this technique of outer and inner catheters, there is no need to sterilize the inner dosimeter catheters.

DIAGNOSTIC RADIOLOGY ABSORBED DOSE MEASUREMENTS:

In the diagnostic range of photon energies, LiF phosphor can over-respond by as much as 40% compared with tissue. However, $Li_2B_4O_7$: Mn is an extremely good match for tissue over this range of photon energies and, by adjustment of the fractional amount of manganese present, the response can be 'trimmed' to match more closely that of air, water or tissue; e.g. Jayachandran [20] suggested 0.34% w/w for air equivalence and Christensen [21] 0.45% w/w. Langmead and Wall [22] found that, using $Li_2B_4O_7$: Mn powder containing 0.15% w/w of manganese, they could measure absorbed dose in tissue, from x-rays of unknown quality, with a predicted error associated with photon energy of not greater than +/- 5% and an overall uncertainty of not more than +/-15%. This is an important characteristic of $Li_2B_4O_7$: Mn phosphor because, while the effective energy of the primary beam can be assessed, at least in air, by half-value layer measurements, the quality of the lower-energy scattered radiation and the magnitude of its contribution to absorbed dose are difficult to assess. $Li_2B_4O_7$: Mn is therefore particularly suited for such measurements. While sensitive solid forms of $Li_2B_4O_7$: Mn, such as extruded ribbons, are commercially available, they are relatively expensive and this tends to exclude them from large-scale measurements programmes. Loose powder is probably most suitable for this application at present.

A. HUMAN PHANTOM MEASUREMENTS:

In contrast with simple homogeneous phantoms, a most useful phantom for absorbed dose measurements in radiotherapy and diagnostic radiology is one which is designed, as far as is practicable, to simulate the structure of human body. The torso and head and neck of such a phantom are shown in figure. In proportion, it is equivalent to an 'average man' 1.75 m tall and weighing 73.5 kg. It is made from tissue-equivalent synthetic rubber and contains a complete human skeleton, lung- equivalent material and airways corresponding to the maxillary sinuses, nasopharynx, trachea, etc. it is composed of a number of 25 mm thick transverse sections each containing a matrix of 5 mm diameter holes spaced 3 cm apart. Each hole can accommodate a dosimeter holder/capsule or a solid plug of tissue- equivalent material. The complete phantom contains over 3000 holes and additional ones can be drilled if required. Suitable Perspex or polythene capsules can each contain approximately 35 mg of powdered phosphor.

Human-like phantoms are extremely useful for absorbed dose measurements in diagnostic radiology where their human form allows not only precise and realistic positioning of 'the patient' in the beam but also positioning of dosimeters to measure the absorbed dose to specify organs, including the gonads. Combined with the use of thermo luminescent dosimeters, they have proved especially useful in the assessment of 'patient' absorbed dose imparted by computerized axial tomography (CAT) (e.g. [4,5]). The recent measurements by Wall were performed using $Li_2B_4O_7$: Mn powder dosimeters contained in plastic containers and inserted in the phantom slices as illustrated in figure. In these examinations, regions of dosimetric interest included not only the section of the patient (phantom) undergoing radiological examination at a particular instant in time but also the adjacent sections which are irradiated as a result of the divergence and scatter of the primary beam. Wall et al [5] also

included measurements of absorbed dose to the lens of the eye, thyroid, gonads and skin. For these they used $Li_2B_4O_7$: Mn powder in polythene sachets.

B. IN VIVO MEASUREMENTS:

While measurements using human-like phantoms are extremely useful in the assessment of absorbed dose in diagnostic radiology, the measurements are not performed under entirely realistic conditions. The information gained from these measurements takes no account of the skill and experience of the radiographer, the quality and suitability of equipment and differences in shape and size of patients. In vivo measurements on patients undergoing routine radiological examinations in hospitals provide a much more realistic assessment under everyday practical conditions. $Li_2B_4O_7$: Mn dosimeters are especially useful for these measurements. They are tissue-equivalent and radio-transparent except on high quality mammograms. In general they do not interfere with the diagnostic quality of the image and cause little inconvenience to patient, radiographer and radiologist.

Langmead et al [23] used $Li_2B_4O_7$: Mn powder dosimeters, which were the same as those shown in figure, for the measurement of absorbed doses to patients undergoing various forms of radiological examinations including cardiac catheterization, barium enemas, intravenous pyelography and mammography. Maximum skin and gonad-absorbed doses were measured. The measurement positions of the 1 X1 cm^2 dosimeters for mammography are shown in figure.

This series of measurements constituted a pilot survey of absorbed doses to patients, and recently this work has been extended to include other radiological techniques.

PC CONTROLLED TLD READER
(Nucleonix make)

PC controlled TLD reader systems is designed in the following paragraphs by referring to the block diagram given below. From the block diagram it can be noticed that ir essentially has the following sub-systems/building blocks.

- LV power supply circuit board/SMPS
- HV power supply circuit.
- Temperature controller circuit PCB.
- Micro controller PCB including .
- ADC, DAC & RS22 circuits.
- I to F connecter for auto ranging.
- PMT, heater transformer, kanthal strip & drawer assembly to load supplies.
- PC system.

Functionality of the hardware circuits can be explained in brief by referring to the following block diagram.

Power supply circuit generates required low voltages (+5V, +12V) to power up, rest of the electronic circuits to function. A continuously variable stable voltage in the range of 0 – 1500V, @1mA with good load. This HV circuit board uses a DC to DC converter switched at 30 KHz, RF frequency to generate HV. HV indication is provided on a front panel DPM and a precision, ten turn dial can be used to set the desired HV for biasing the PMT.

Current output from the PMT is converted to frequency output by C to F converter circuit. These pulses are counted in a serial counter under programme control in microcontroller board.

Microcontroller board essentially has an ADC, DAC, EEPROM, and a serial counter apart form the serial port & embedded code. Under the command instruction from personal computer through serial port, the firmware built-in initiates hardware functional cycle which essentially involves heating of the kanthal strip at the programmed heating rate, till it reaches required set temperature & clamping it for the desired duration if defined & follow the natural cooking cycle till the end of run time defined. During this time both temperature output (as read from the amplified thermocouple amplifier built-in into TC board & through ADC built-in into controller board) and TL intensity, (as read & recorded by serial counter through C to F converter), are logged & stored into EEPROM sequentially in to 200 channels (locations). Also DAC is programmed & incremented and output is fed to TC board to achieve programmed heating. As the programmed heating takes place, TL intensity is read.

Personnel computer system with front end, TL glow curve data acquisition & analysis software (in VB) provides the required graphics user interface. Easy to use command buttons have been defied on the screen.

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Personnel computer system with front end, TL glow curve data acquisition & analysis software (in VB) provides the required graphics user interface. Easy to use command buttons have been defied on the screen.

SOFTWARE FEATURES

The software features provided include

- Temperature calibration
- System configuration
- Acquisition and processing of 200 channel TL data for
- Fixed Wt. Sample (disks, crystals and micro rods etc.)
- Powder samples
- Saving the acquired data to a disk file for further access
- Generation of reports
- Fixed Wt. Sample
- Powder samples
- Overlapping of glow curves for different samples.
- Subtraction of background from the data acquired

User is provided with a menu driven graphic user interface to facilitate the user to interact with the system. This data acquisition and analysis software essentially does the following things.

TEMPERATURE CALIBRATION:

The facility of doing the temperature calibration is provided through software using which the user can calibrate the system at threee temperatures which makes the system to produce accurate results.

SYSTEM CONFIGURATION:

- It facilitates the user to set the temperature profile from the computer connected to the system thru serial port of the computer.
- It also allows the user to determine the heating rate to which the TL phosphor sample placed on the khanthal strip is subjected to achieve the required glow curve.

Fig above shows temperature profile configuration dialog box with a typical temperature profile. On user's request to set the temperature profile the dialog box pops up with default profile loaded in to it. If the user wishes to change the profile he can do it by just keying in the values, such as rise time, set temperature, clamping time and run time etc.

ACQUISITION AND PROCESSING OF 200 CHANNEL TL DATA :

Once the required temperature profile is set the user can go directly for acquisition of 200 channels TL data for either fixed Wt. Samples or powder samples. To change the sample type either fixed Wt. Samples or powder samples user has to just click on the menu option sample type and select the required sample type. After acquisition is done the data from the system is automatically downloaded to the computers memory and a glow curve is plotted with the downloaded data with a line indicating the temperature profile and a curve intensity Vs time. As shown below.

SAVING/OPENING THE ACQUIRED DATA TO A DISK FILE FOR FURTHER ACCESS:

User can save the glow curve to a disk file by a click on the menu option provided in the software menu bar. The file thus saved can be recalled at any point of time for analysis and at a max of 20 glow curves can be overlapped on one another to compare the results. User can find the TL intensity, channel number and temperature at a particular point on the curve just by clicking on any point on the curve. A typical screen with two glow curves overlapped is shown below.

SMOOTHENING OF ACQUIRED CURVE:

The plotted curve can be smoothed for error correction using the menu option or the button provided on the toolbar. Three point smoothening technique is used for this purpose.

MULTIPLICATION:

The height of the glow curve can be varied by multiplying the TL intensity with a multiplication factor.

SUBTRACTION OF BACKGROUND:

User can subtract the background data from the original glow curve using the menu option subtract which will ask the user to select the original file and background file and it automatically subtracts the background data from the original data and plots a glow curve for users analysis.

Equipments required for Performing the Thermoluminescence Experiments

EQUIPMENT / SYSTEM:		TYPE
1.	TL Reader System	**TL1009(I)**
2.	Personnel Computer System	
3.	TL phosphors (disc & powder)	
4.	Annealing oven	
5.	UV source (80W, wave length: 360 nm)	
6.	Irradiation source : Sources Sr-90, β source : 50 - 100 mCi or γ - source 500mCi or X-ray source or X-ray diagnostic machine (available from a near by hospital Diagnostic centre) or Cobalt - therapy machine available at any of the cancer hospitals, could be used for this purpose.	

Most of the above mentioned equipments are manufactured and or supplied by:

M/S NUCLEONIX SYSTEMS
Plot No:162 A & B, Phase II, I.D.A.Cherlapally, Hyderabad - 500 051.
Ph : 91-040-27263701, Fax : 27262146, e-mail : info@nucleonix.com

THE TL MEASUREMENTS

(Using an integral Thermoluminescence reader TL 1009I)

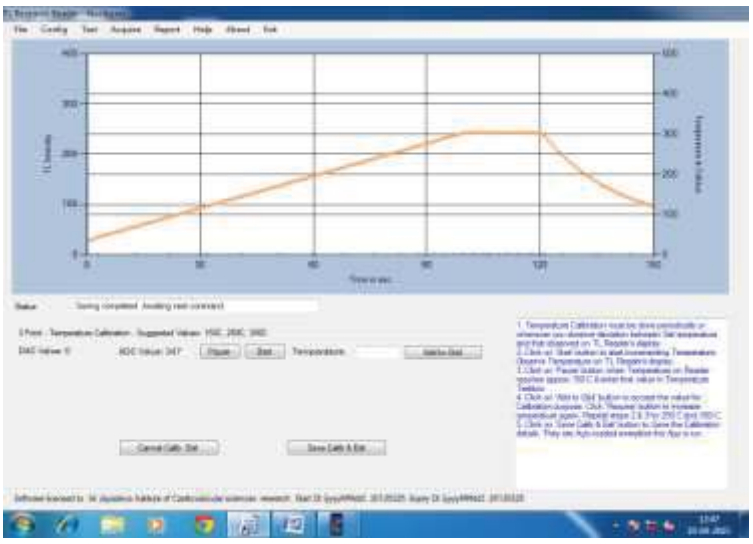
1. Put on the High Voltage at least 30minutes before starting TL recording.
2. Wait at least 5 minutes between the two readings, which is necessary to cool down the Kanthal Strip and the brass Studs to 50°C
3. Equal amounts of sample by weight or volume should be taken for TL measurements. For equal volume one can use the volume dispensers. For weighting precision balance is to be used.
4. The voltage to the Photomultiplier should be constant at –700V.
5. Do not open the drawer while the heating is on.
6. Do not open the Photomultiplier in the light, which may damage the dynodes.
7. Clean the kanthal strip every time with acetone if you are measuring the TL of the organic materials.
8. Check the sensitivity of the equipment with standard powder ($CaSO_4$: Dy) supplied by the manufacturer or light source (Ni-63).
9. Use the same heating rate in the range from 2° C/sec to 40° C/sec for the same set of sample.

DEFAULT SETTINGS OF TL1009 (I) :

1. Switch ON the instrument.
2. Connect the communication cable between PC to instrument.
3. Switch ON the HV, set the operating voltage of PMT.

3 POINT TEMPERATURE CALIBRATION:

Switch ON the heater and do the 3 point temperature calibration increase the DAC value appropriately temperature will be increase. The temperature display shows 150°C enter the temperature in appropriate box as shown below then resume the next point. Then increase the temp to 250°& 350°.



EXPERIMENTS/ MEASUREMENTS WITH TLD READER

EXPERIMENT – 1

AIM :
Study of the TL characteristics of various commonly available material and calculate the E,S and b values.

INTRODUCTION :
The following materials are selected (Commonly available) for the experiment.

1. $CaSO_4$: Dy a commercial dosimetry phosphor (powder as well as discs)

2. Fluorescent lamp phosphors (collected from the breaking of a tube light.

3. Sodium Chloride or NaCl (common salt) and salt from USA.

4. Al_2O_3 is other good dosimetric mineral.

5. Natural quartz is mineral dosimeter one can get the quartz very easily around us (collect the sand and separate the glassy material, clean it and heat it upto 400^{o}C for an hour and irradiate and record TL).

All the above materials are collected and grinded in an agate motor and pestle to get powder and annealed to have zero residual TL, by heating upto 300^{o}C for an hour, on an SS plate, placed inside a industrial furnace. All the samples are given a test dose of 5 m.Gray ($\simeq$ 500mR)from a Co 0-60 / Cs-137 gamma source.

20 mg of weighed irradiated powder (Equal volume) sample was taken for TL measurement.

Put the High Voltage to (-700V)D.C, at least 20 minutes before starting TL recoding. Waiting tie of 5 minutes between the two readings, is necessary to cool down the Kanthal Strip and the brass studs to 50^{o}C or less, before another acquisition cycle can be initiated.

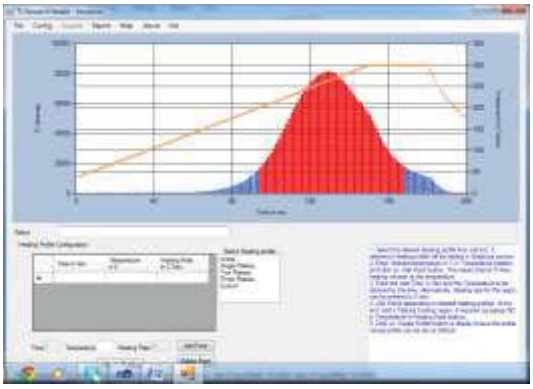
Note : The High voltage selected depends on the sensitivity of the PMT, used in the system.

EXPERIMENTAL PROCEDURE:

Step 1 : Make default connections as described under system inter connections, in this manual / user instruction manual.

Step 2 : Switch on the system & go through the four point temperature calibration procedure as described in the user manual / software manual. Also set the operating voltage as desired (-700V typical)

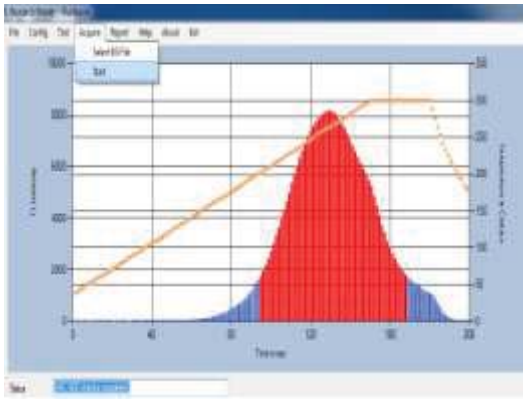
Step 3 : Click on configure menu & create load a profile (previously saved, if any) or create a fresh profile by entering the parameters such as time, temperature or heating rate. Then click on "create profile" to save the profile.



Step 4 : Pull the drawer assembly & after allowing initial kanthal strip temperature to be less than 50°C, place accurately weighted powder sample / disc / micro-rod / pellet etc., at the centre of kanthal heater strip.

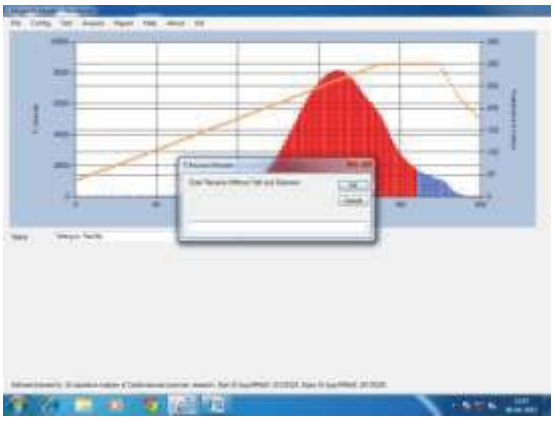
Step 5 : Now start acquisition by mouse click on "Acquire" menu and click on "start" button shown below

.



Step 6 : This initiate acquisition process & glow curve gets recorded in the TL Reader unit in controller card EEPROM chip.

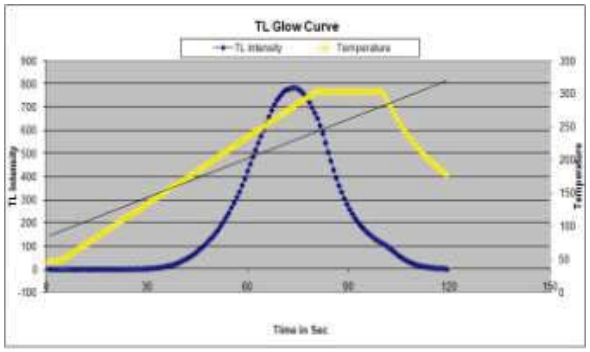
Step 7 : At the end of Acquisition TL glow curve gets into PC for visualization & for further processing. For saving the TL glow curve click on file icon, you will see pop-up menu as shown below.



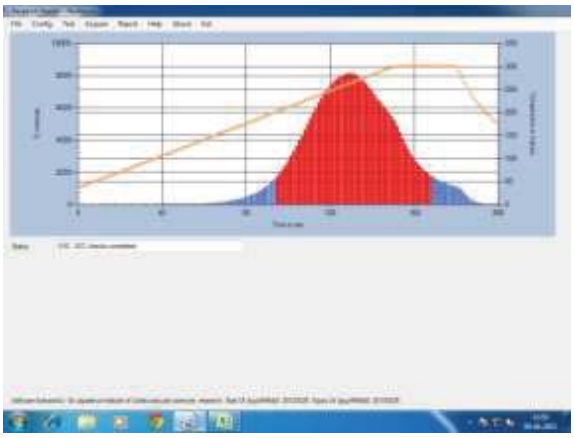
Step 8 : After saving this glow curve, re-run to see residual TL if any. It shall be less than 10% of the area of the first peak, if TL emission is complete in the 1st cycle.

Step 9 : Allow temperature to fall to <55°C & brush-out the powder sample into collection tray just below the heater strip. Acquire with the same **'temperature profile'** for background, & save the background glow curve into another file.

Step 10 : Now obtain net glow-curve as indicated below after subtracting BG file which can be shown below.



Step 11 : For area under the glow curve analysis select the first point at the rising point of the glow curve and press the shift key and select the second point on the glow curve. Fig shows the area under the glow curve. (Select area becomes shaded in red color). Also it reports integral counts (area under the peak)



Step 12 : Figures indicate glow curves recorded with different TL Phosphors.

Step 13 : Follow the same steps as described above for recording the TL glowcurves for different TL phosphors. Following table shown the TL peak temperatures of different phosphors.

Fig.No	Name of the sample	TL peak temperature in ^{o}C
1	$CaSO_4$: Dy	237
2	Salt (Catch) India	127, 211
3	Salt (USA)	175
4	CaF	140, 247
5	A12O3	140, 280
6	Quartz	89, 134
7	Tube Light coating material	135

EXPERIMENT - 2

Aim to study the TL growth of $CaSO_4$: Dy, 235^{o}C peak & Linearity of $CaSO_4$: Dy
Commercial TL Dosimetry Phosphor $CaSO_4$: Dy is taken for TL measurements after various doses of gamma irradiation. The TL curve 235^{o}C is selected for the present study.

AIM

Study of the $CaSO_4$: Dy 235^{o}C peak and linearity of $CaSO_4$: Dy with different doses

INTRODUCTION

Commercial TL Dosimetry Phosphor $CaSO_4$: Dy is taken for TL measurements after various doses of gamma irradiation. The TL curve 235^{o}C is selected for the present study.

Each time 20mg weight gamma irradiated powder is taken for TL measurement.

The gamma dose given is 1,1.5, 1.75, 2, 4 and 8 Rads from a Cs-137 calibrated gamma source.

Follow the steps as explain in experiment No : 1

Fig.1. represent the TL of 235^{o}C TL peak growth. In graph on X-axis temperature and on Y-axis TL intensity are plotted. Total integral counts represent the glow curve under the peak. For the effect of dose verifying select the different irradiated glow curves (over lapped curves)

Fig.2. represents the effect of dose on TL phosphor.

Fig.3. represents the TL glowth effect of $CaSO_4$: Dy

Note : One can take any good TL dosimetric material for this type of study ad mentioned in the experiment No.1

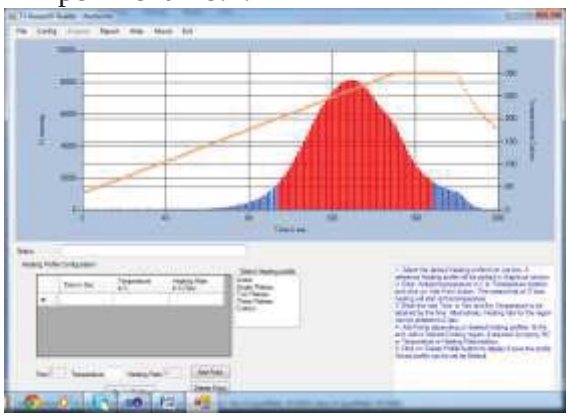
EXPERIMENTAL PROCEDURE :

Step 1 : Refer to step 1 of Experiment No.1

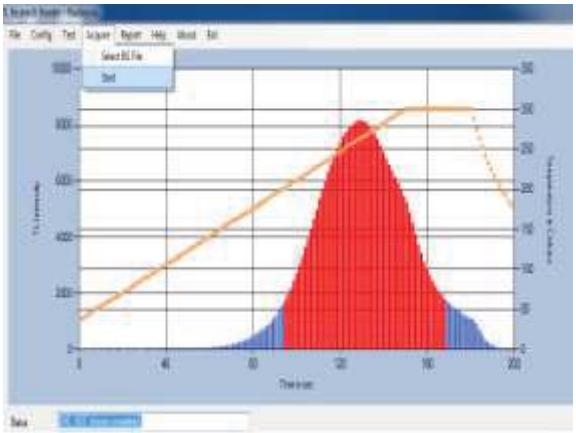
Step 2 : Refer to step 2 of Experiment No.1

Step 3 : Pull the drawer assembly & after allowing initial kanthal strip temperature to be less than 50°C, place accurately weighted powder sample / disc / micro-rod / pellet etc., at the centre of kanthal heater strip.

Step 4 : Refer to step 3 of Experiment No.1.



Step 5 : Now start acquisition by mouse click on 'ACQ' (A) button as shown below.



Step 6 : Refer to step 6 of Experiment No.1

Step 7 : Refer to Experiment No.1 Step 7

Step 8 : After saving this glow curve, re-run to see residual TL if any. It shall be less than 10% of the area of the first peak, if TL emission is complete in the 1st cycle.

Step 9 : Refer to Experiment No.1 Step 9

Step 10 : Now obtain net glow-curve as indicated below after subtracting BG file which can be shown below.

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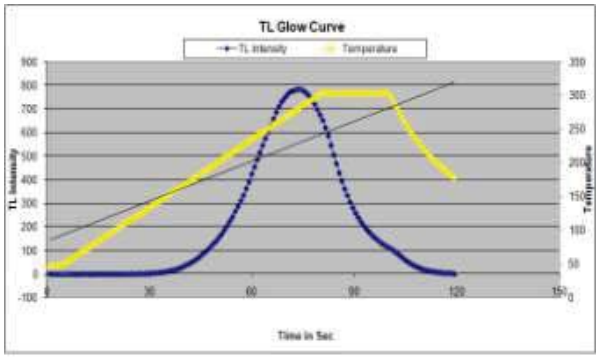
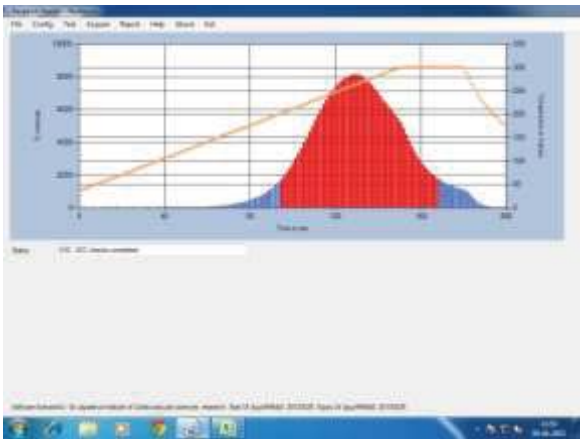
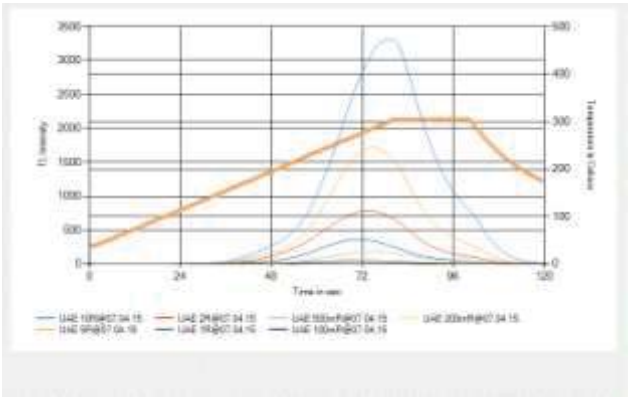


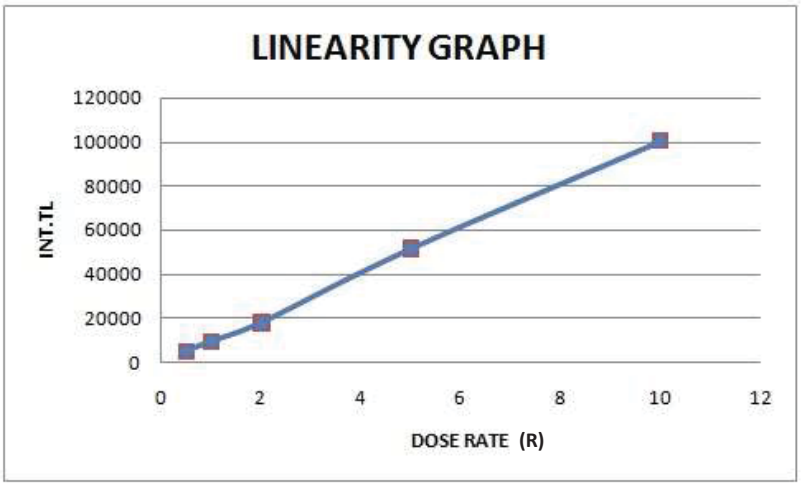
Step 11 : Refer to step 11 of Experiment No.1



Step 12 : Do the same procedure as described above for 1,1.5, 1.75, 2, 4 and 8 Rads.

Step 13 : Following figures shows the TL glow curve of $CaSo_4$:Dy&linearity of $CaSo_4$:Dy





Note : Temperature profile should be same for different irradiate sample.

EXPERIMENT - 3

Aim to study the total scatter of X-ray radiation

Aim
To study the irradiation of X-ray scatter and linearity of TL growth effect.

Introduction
Take CaSo4 : Dy or any TL Phosphor for this experiment. Take each time 20mg weight for X-ray irradiated powder is taken for TL measurement.

The X-ray dose given is 100, 200, 300, 500, 600 exposure from a X-ray unit.

Plot TL intensity Vs number of exposure will give the effect of X-rays on TL phosphor.

EXPERIMENTAL PROCEDURE :

Step 1 : Refer to step 1 of Experiment No.1

Step 2 : Refer to step 2 of Experiment No.1

Step 3 : Refer to step 3 of Experiment No.2

Step 4 : Refer to step 3 of Experiment No.1

Step 5 : Refer to step 5 of Experiment No.1

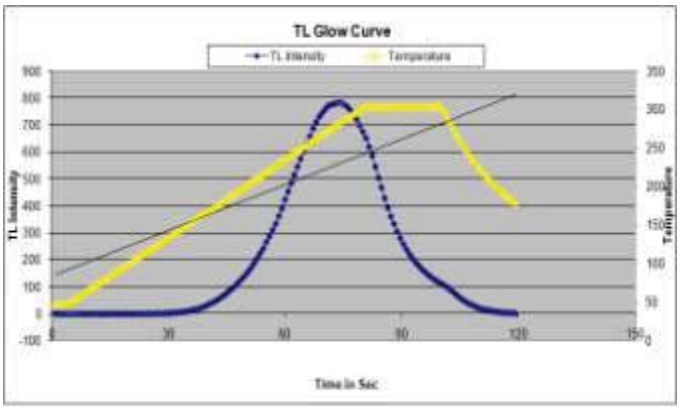
Step 6 : This initiate acquisition process & glow curve gets recorded in the TL Reader unit in controller card EEPROM chip.

Step 7 : Refer to step 7 of Experiment No.1

Step 8 : After saving this glow curve, re-run to see residual TL if any. It shall be less than 10% of the area of the first peak, if TL emission is complete in the 1st cycle.

Step 9 : Refer to step 9 of Experiment No.1

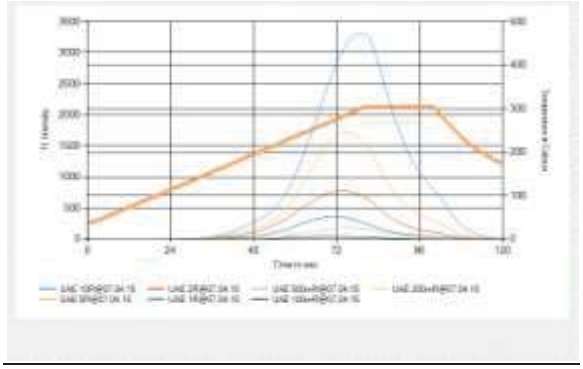
Step 10 : Now obtain net glow-curve as indicated below after subtracting BG file which can be shown below.

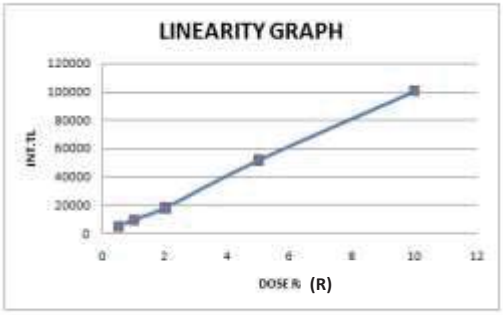


Step 11 : Refer to step 11 of Experiment No.1

Step 12 : Do the same procedure as described above for 10, 15, 20, 25, 30 sec.

Step 13 : Following figure shown the effect of X-ray Scatter on $CaSo_4$: Dy





Step 14 : Put a TLD containing plastic bags around the X-ray baggage screening unit in the main port. study TL after 1, 2, 4, 6 & 10days. Plot TL intensity / number of days.

Note : Temperature profile should be same for different irradiate sample.

EXPERIMENT - 4

To study the UV Exposure on TL Phosphors

AIM

To study the UV Exposure on TL Phosphors and Linearity.

INTRODUCTION

Commercial TL Dosimetry Phosphor $CaSO_4$: Dy is taken for TL measurements.
Take the TL phosphor for each time 20mg.

Put the sample bottom of UV lamp, for each sample take the different time intervals (5, 10, 20, 30 and 60minutes).

Plot the TL temperature Vs TL intensity

EXPERIMENTAL PROCEDURE :

Step 1 : Refer to step 1 of Experiment No.1

Step 2 : Refer to step 2 of Experiment No.1

Step 3 : Refer to step 4 of Experiment No.1

Step 4 : Refer to step 3 of Experiment No.1

Step 5 : Refer to step 5 of Experiment No.1

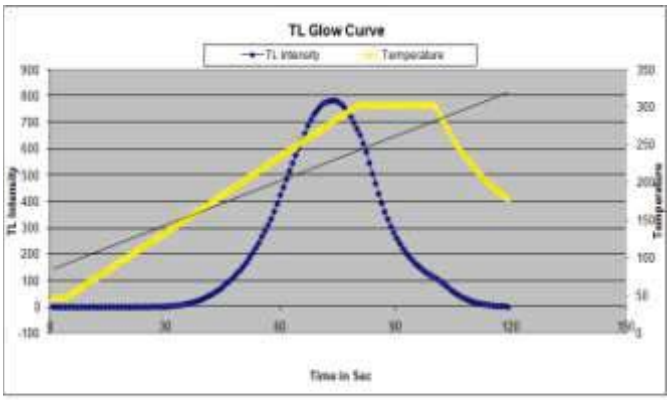
Step 6 : This initiate acquisition process & glow curve gets recorded in the TL Reader unit in controller card EEPROM chip.

Step 7 : Refer to step 7 of Experiment No.1

Step 8 : After saving this glow curve, re-run to see residual TL if any. It shall be less than 10% of the area of the first peak, if TL emission is complete in the 1^{st} cycle.

Step 9 : Refer to step 9 of Experiment No.1

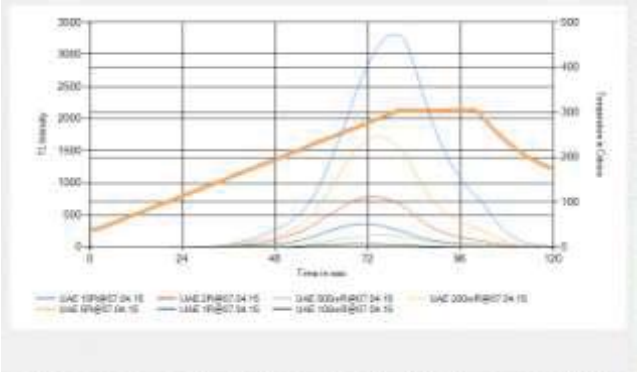
Step 10 : Now obtain net glow-curve as indicated below after subtracting BG file which can be shown below.

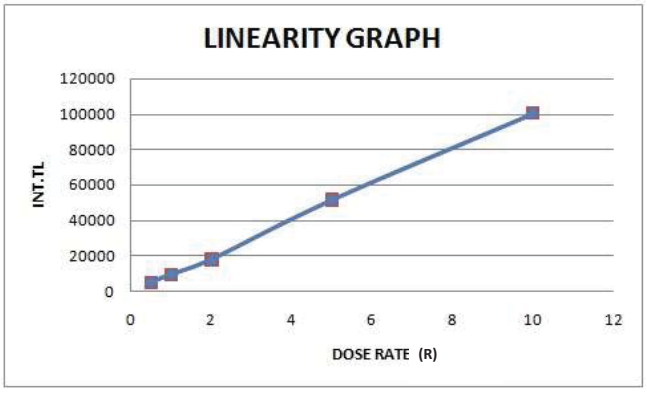


Step 11 : Refer to step 11 of Experiment No.1

Step 12 : Do the same procedure as described above for 10, 20, 30 and 60 minutes.

Step 13 : Following figure shown the linearity of $CaSo_4$: Dy with UV exposure.





Note : Temperature profile should be same for different irradiate sample.

The following TL curves of gamma irradiated common materials available in and around us.

Fig.1 TL GLOW CURVE OF CaSO4:Dy

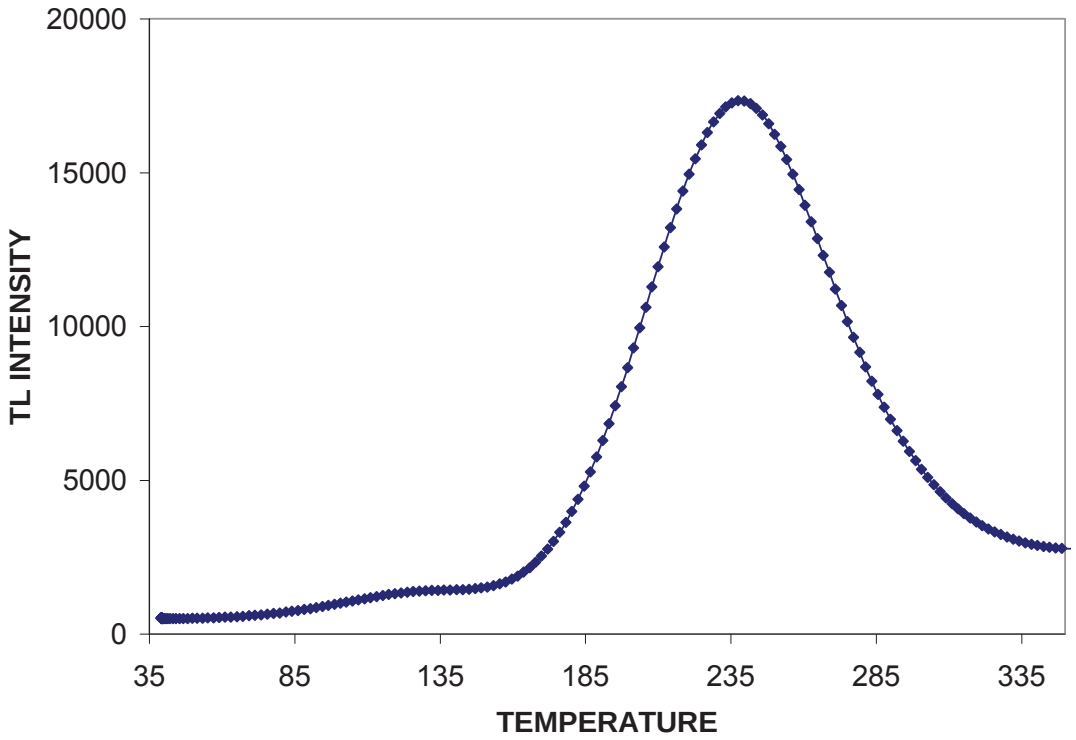


Fig. 2. TL of gamma irrdiated IndianSalt (Catch)

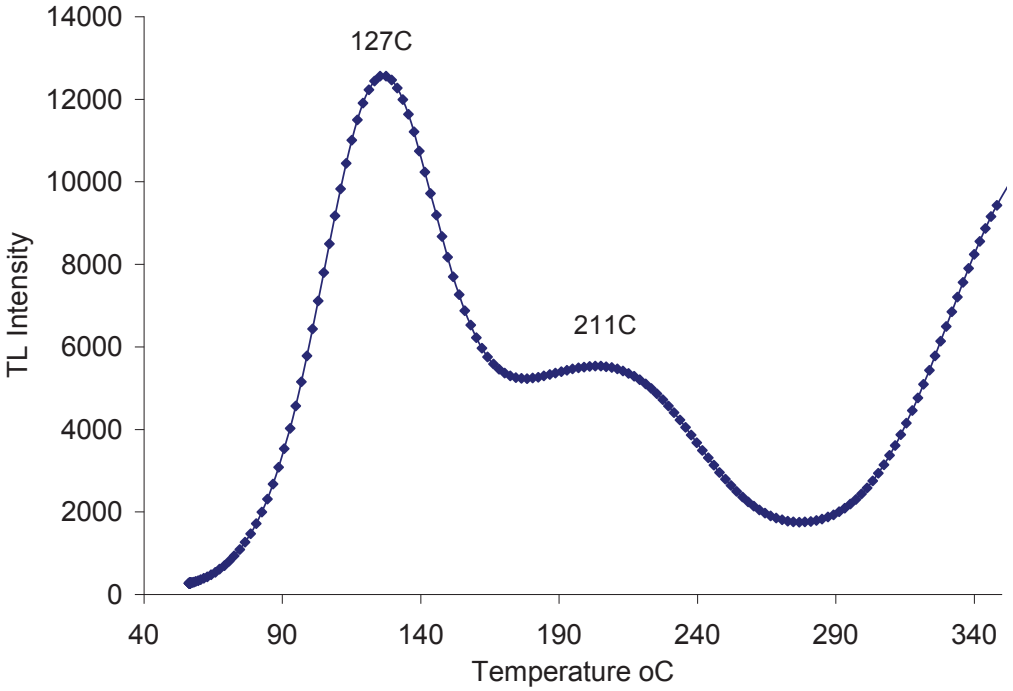


Fig.3 . TL of Salt

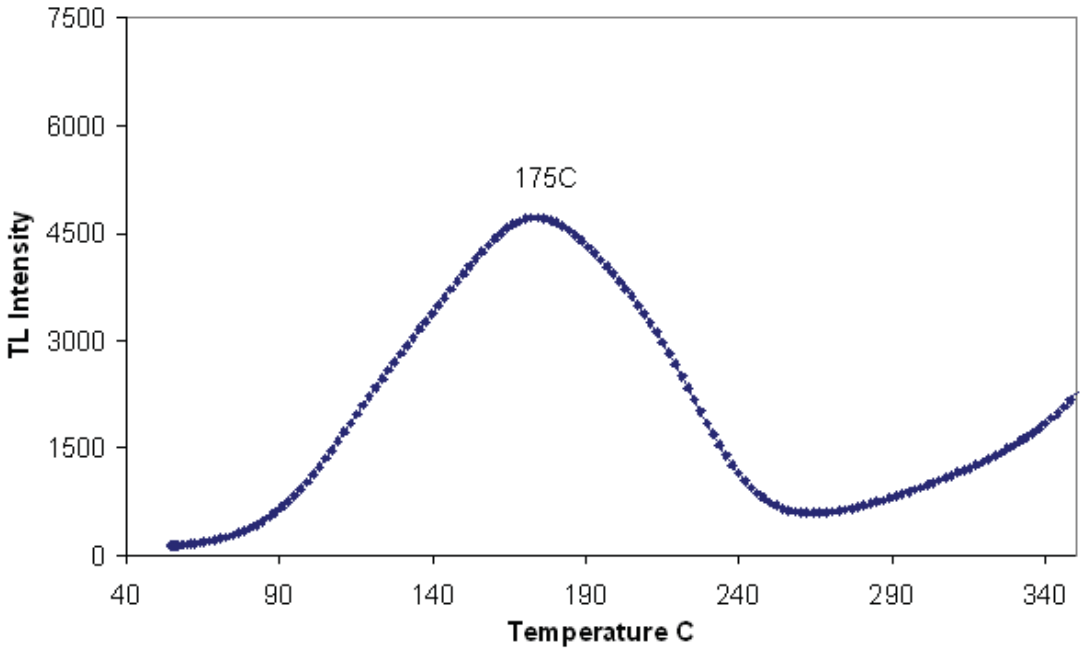


Fig.4. TL of gamma irridaited CaF

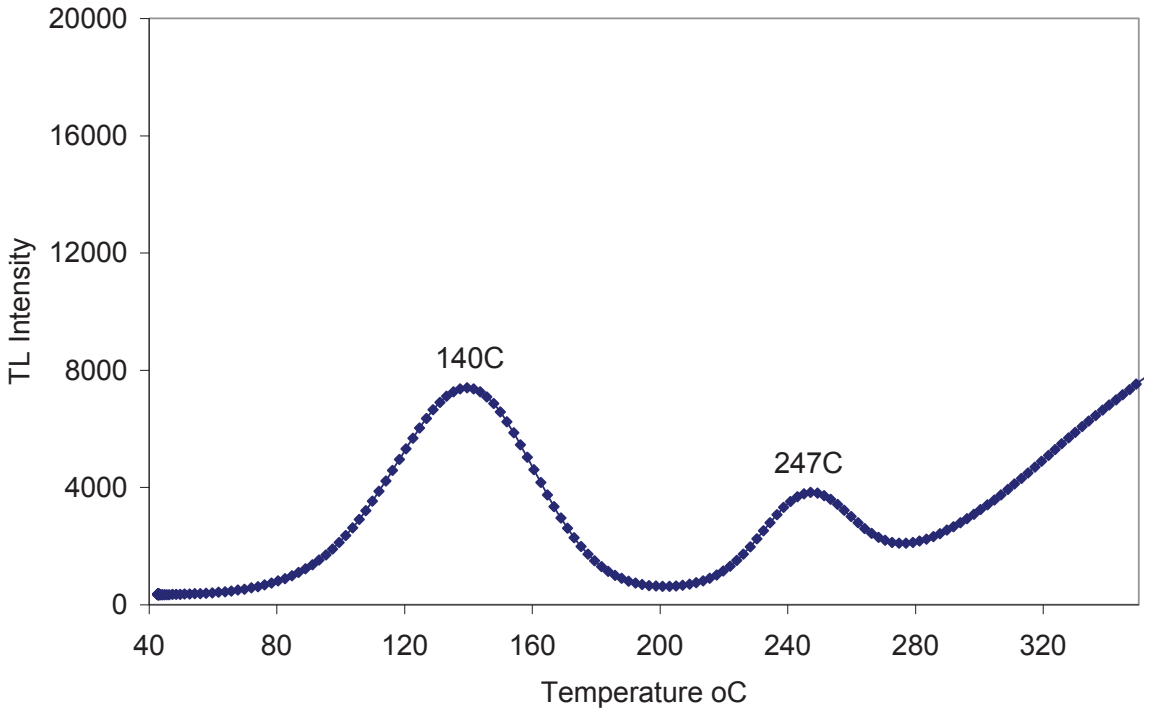


Fig.5.TL of gamma irridaited Al2O3

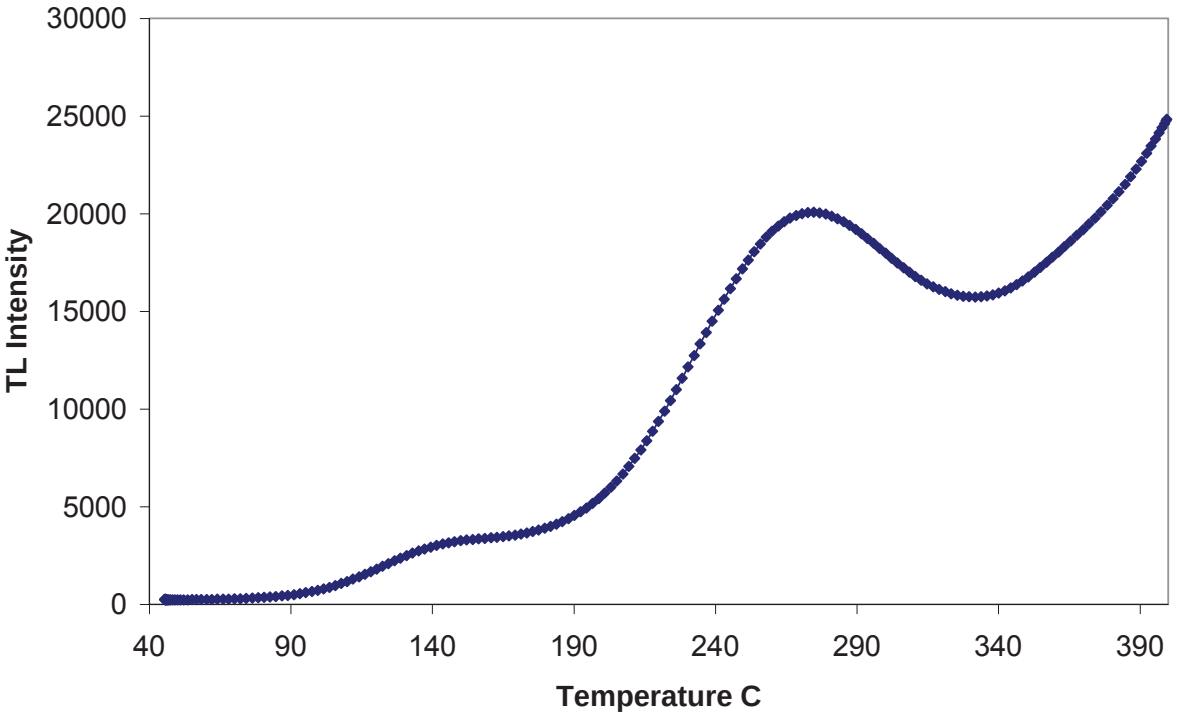


Fig.6. TL of 10Gy gamma irridaited quartz

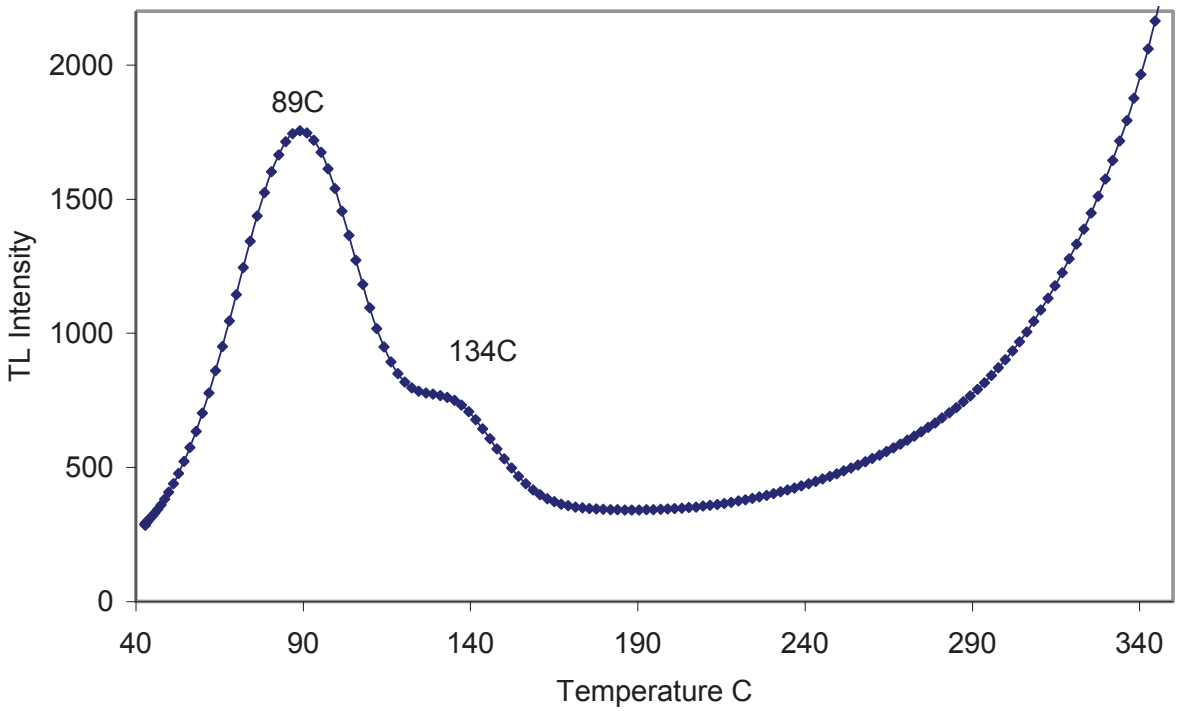
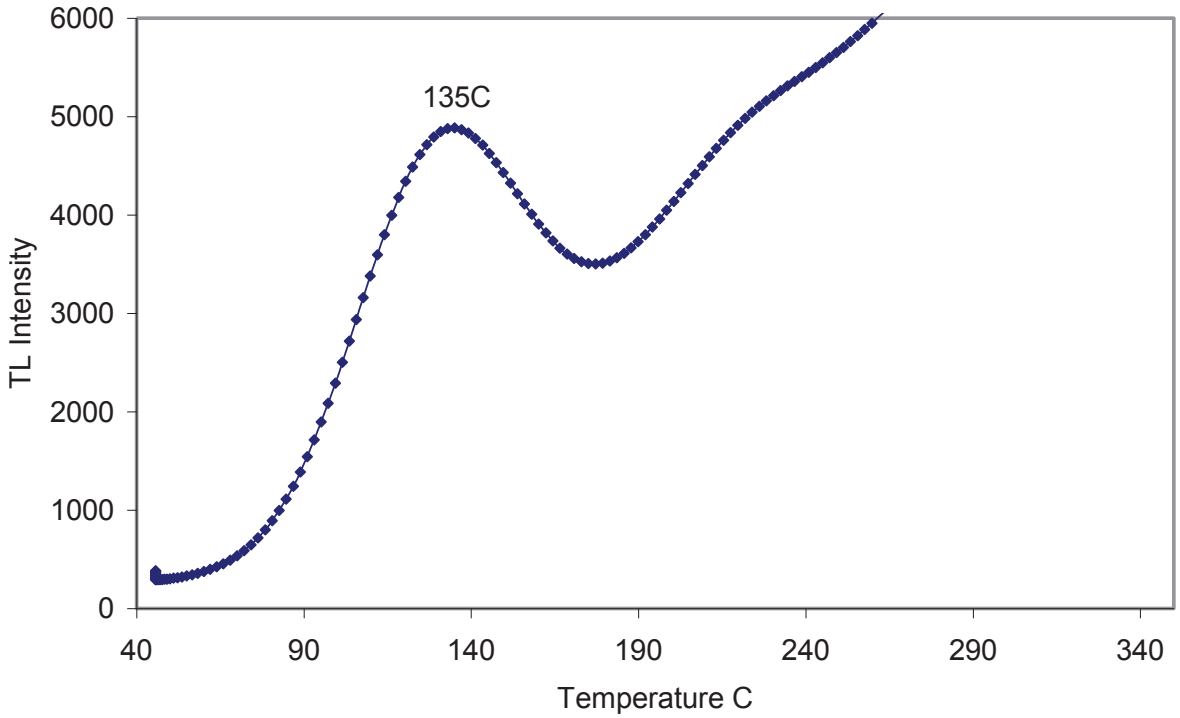


Fig.7.TL of gamma irridiated Tube Light Coated Material



The tube light coating materials are good Photoluminescence materials called phosphors. One can break any lamp carefully and collect the Phosphor irradiates and study the thermoluminescence.

Salt from market different brands can be collected and dried at 200^{o}C for an hour and irradiate with any ionizing radiation and study the thermoluminescnec.

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1. Applied Thermoluminescence Dosimetry, Lecturers of a course of a held at the joint Research Centre, Ispra, Italy, 12-16 Novermber 1979, Ed.by M OBERHOFER and A SCHARMANN, Published for the commission of the European Communities by Adam Hilger Ltd, Bristol.

2. Handbook of Thermoluminescence, Claudio Furetta, World Scientific Pub. Co., 20003.

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5. Wiedemann E and Schmidt GC 1895 Ann. Phys. Chem 54 604

TLD Applications in Radiation Oncology

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Chapter-III

Thermoluminescent Dosimetry (TLD) has been developed during 1960-70 for various applications in medicine and industry. A brief list of applications specific to radiation oncology is given here. In radiation oncology dosimetric accuracy demanded is on the order of 2-5%. TLDs offer a clear solution since their precision meets this criteria.

1. **Calibration checks, different institutions, mailed Dosimetry- national standard maintenance:**

   The Radiation Safety Systems Division, BARC, Mumbai, provides national dose-inter comparison service for hospitals to check their machine calibrations independently using precisely controlled mailed TLD dosimeters. Typical service includes cobalt-60 beam output check for gamma photon beam and Linac output check for photon and electron beams. Similar more frequent service could be provided by the International Cancer Center at Mahatma Gandhi Memorial Medical Trust, Pedaamiram, Bhimavaram, A.P. to the Teletherapy Centers in that region since they have recently established a Nucleonix TLD system with LiF and CaSO4:Dy in the form of discs and chips. The Center also has a calibrated Secondary Standard Dosimeter traceable to the National Standards Laboratory at BARC, Mumbai. Intern comparison program is essentially a form of external audit of the above calibrations and it should be made mandatory for Quality Assurance of proper Radiotherapy Treatment. It is essential that both the systematic and random errors involved are quantified.

   Preliminary results of different measurements carried out with CaSO4:Dy teflon discs and LiF (TLD 100) chips and discs in the International Cancer Center are given as Appendix 'A' to this report. It should be mentioned that the measurements are from initial experiments carried out with the Nucleonix TLD reader recently procured by this Center. All the experiments mentioned in the Appendix need repetition and further careful investigation.

2. **Treatment planning accuracy verification:**

   The use of IMRT for patient treatments involves multiple MLC segments with odd beam shapes. Most segments deliver dose in electronic dis-equilibrium conditions. TLDs (particularly LiF) is aptly suitable to check the target dose using suitably designed multipurpose phantoms (made of tissue equivalent materials or Solid water, or PMMA sheets).

3. **Patient specific Dosimetry:**

   Physicians request physicists to measure dose at certain anatomic positions of some patients. This is usually referred as Special physics consult. Examples of these locations on patients are a) surface dose on breast, b) dose to the scrotum for very young male patients, c) Thyroid dose d) dose to contra-lateral breast etc. In general treatment planning systems cannot calculate dose outside the radiation field accurately.

   Due to the complex calculations required to obtain dose distributions and their inherent difficulties, combined with clinical issues such as patient movement, ***in vivo*** **dosimetry** is the optimal way to check the actual dose delivered to the patient. It is also important to know the dose delivered to a patient accurately for treatment records for comparisons of

treatment results, patient statistics and to assess side effects. These in vivo systems can have relatively large uncertainties, which should be assessed before using them. While in vivo systems are useful for individual patient measurements, they should not substitute for an adequate QA program.

TLDs serve an important role in this regard.

4. Brachtherapy Physics:

Small Brachytherapy sources such as Iodine seeds for prostate implants, iridium seeds in ribbon form, HDR sources etc. all use encapsulation. The dosimetry of these sources offer a challenge, since the exact amount of materials used for encapsulations is not known even to the manufacturer. Even for doing Monet Carlo simulations, one needs a precise knowledge of the source configuration. In general there are two unknowns in a given brachytherapy source, the activity of the source inside the capsule and the exact amount of encapsulation. It is not possible to solve this by any direct means without breaking the source. TLDs are often used to map the dose distribution in water equivalent medium and the data are fitted using theoretical calculations. Once accurate dosimtery is obtained, the data are fed to treatment planning computers. TLDs play a major role in the assessment of various TG-43 factors for a given brachy source.

5. Diagnostic X-rays

In X-ray diagnostics, TL dosimeters are commonly used for determining absorbed doses to patients, as well as in phantom studies. For this study, TLD-100 (LiF:Mg,Ti) TL dosimeters could be used to measure the absorbed doses. The measurements could be performed in a Alderson-Rando phantom, which is a commercially available phantom with anatomical inhomogenities in respect to the lungs and skeleton. In the irradiations, the TL dosimeters are to be fixed into the holes of the Alderson-Rando phantom so that the flat surface of the detector always faced the beam. The absorbed doses to various organs of the phantom are then derived from the doses of the reference points, i.e. those points measured directly with TL detectors or interpolated from them.

6. Research:

There are very many applications of TLD for research in radiation oncology physics. For narrow beams used in radiosurgery, ionization chambers are too large in size and hence cannot be used. Some of the stereotactic beams are very narrow, i.e. less than few mm in diameter. TLDs provide a clear advantage in the dosimetry of narrow beams. For various external beam and brachytherapy applications, physicists use special phantoms and use TLDs to map the dosimetry and compare with calculations.

PRELIMINARY EXPERIMENTS USING THE NUCLEONIX TLD SYSTEM

The following experiments are carried at International Cancer Center, Pedaamiram, Bhimavaram using the Nucleonix TLD reader.

International Cancer Center
Mahatma Gandhi Memorial Medical Trust
PedaAmiram, Bhimavaram, AP 534204

The reader has the ability to be controlled through a PC. The heating cycles are controlled by giving a chosen ramp temperature rate in °C/s (range 2 - 40° per second) for a steady temperature cycle. Most importantly, this unit collects the entire glow curve in digital form into a file in the computer. The file with extension .glo is in ASCII format and is accessible through excel spread sheet.

The Center has also acquired different TLD detectors; namely $CaSO_4$:Dy discs, (sizes 13.5 mm dia x 0.8 mm thick and 6 mm dia x 0.8 mm thick); LiF TLD-100 chips of size 3.2 x 3.2 x 0.9 mm and LiF TLD100 Teflon discs of size 1 cm dia.

Some of these detectors were irradiated at MNJ hospital, Hyderabad.

1. Calibration

$CaSO_4$ dosimeters were irradiated at MNJ Hospital using their Cobalt Teletherapy machine. Three dosimeters at each dose value, viz., 5, 25, 50, 100, 200, 500 cGy were irradiated. Glow curves were obtained. The signal was integrated between 140-250°C. The background for a control sample was acquired and was subtracted from the sample signals. Fig. 1 below shows a glow curve from a CaSO4:Dy disc exposed to a dose of 100 cGy from cobalt-60 gammas. In addition the temperature profile used for the glow curve is also shown in yellow color.

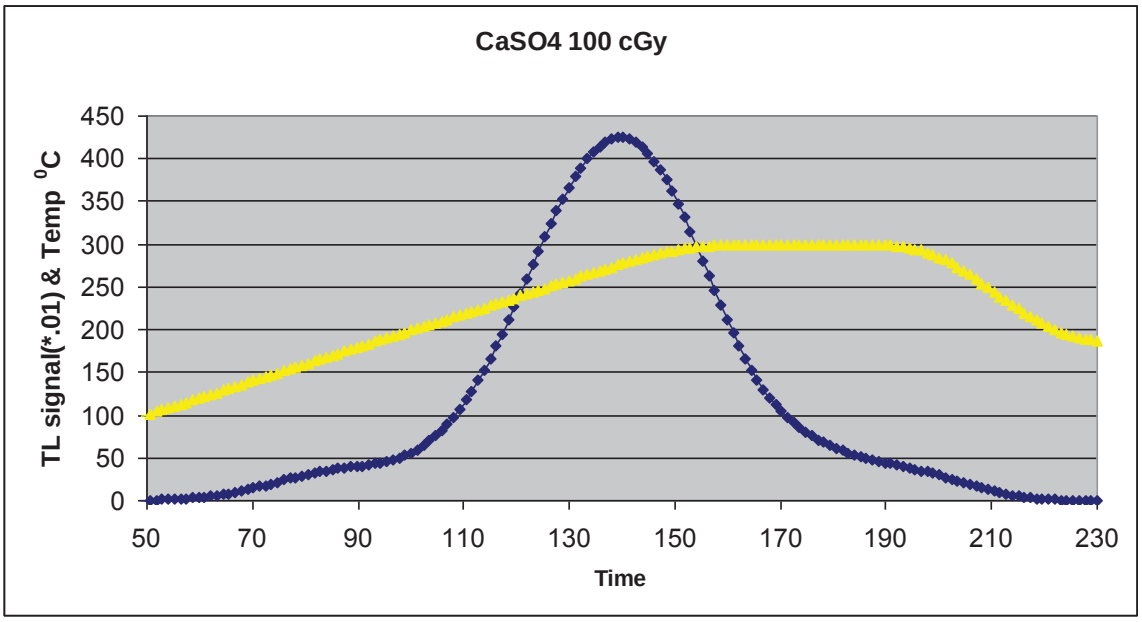

Fig. 1: Glow curve (blue) for $CaSO_4$:Dy and temperature profile (yellow) used to read TL

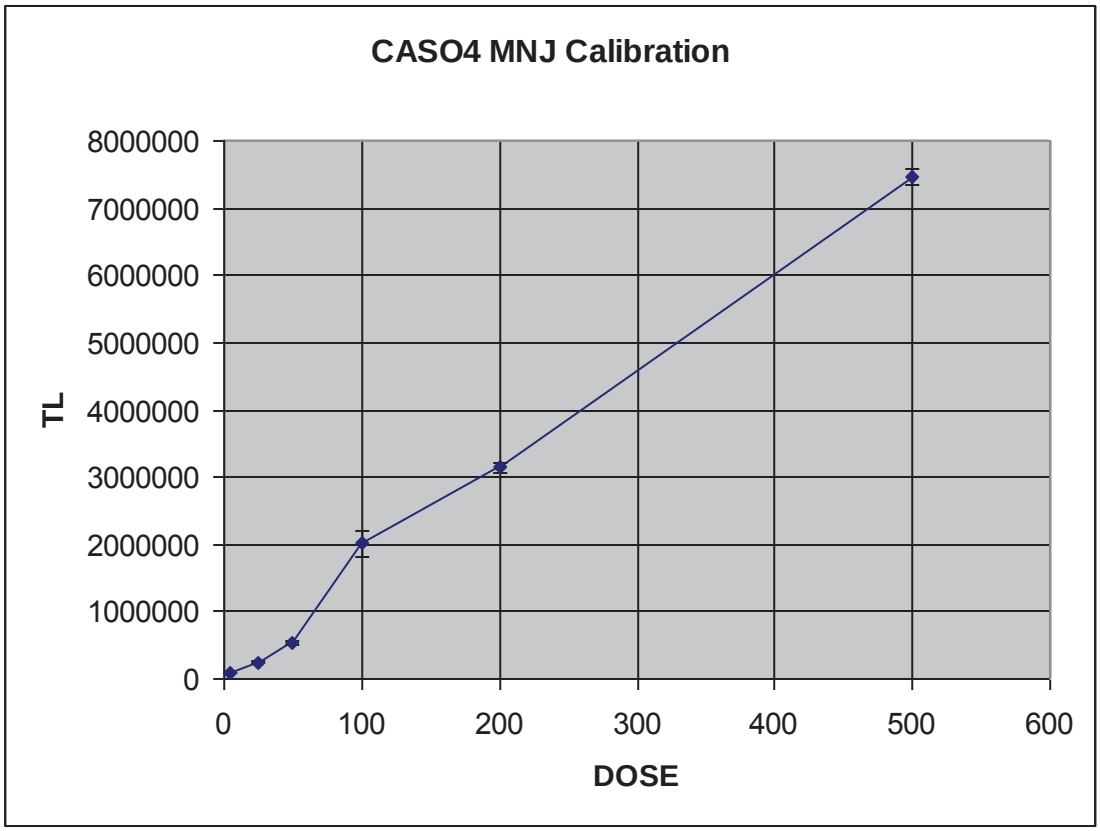

Fig. 2: Calibration plot - dose in cGy vs TL output

Fig. 2 above shows calibration curve obtained with $CaSO_4$ discs exposed to cobalt-60 gamma rays at MNJ Hospital. Each point is an average of 3 dosimeter readings. Also shown at each point are the standard deviations as error bars. It is to be noted that the point at 100 cGy even though looks higher, it has an uncertainty of only 8%. The higher response from these teflon $CaSO_4$:Dy discs, hence, is assumed to show supralinear behaviour between 50-100 cGy and again follow linearity in the range 100-500 cGy. However, this conclusion needs further investigation.

Fig.3 shows a similar calibration plot for LiF TLD-100 chips irradiated with Cobalt-60 teletherapy machine at this Cancer Center. It can be seen that the response is linear. Also note that response of each chip for a given dose can be different. In this experiment, the chips have not been pre-sorted for uniform response. In principle, chips are to be grouped based on acceptable percent deviation of their TL response for the same dose.

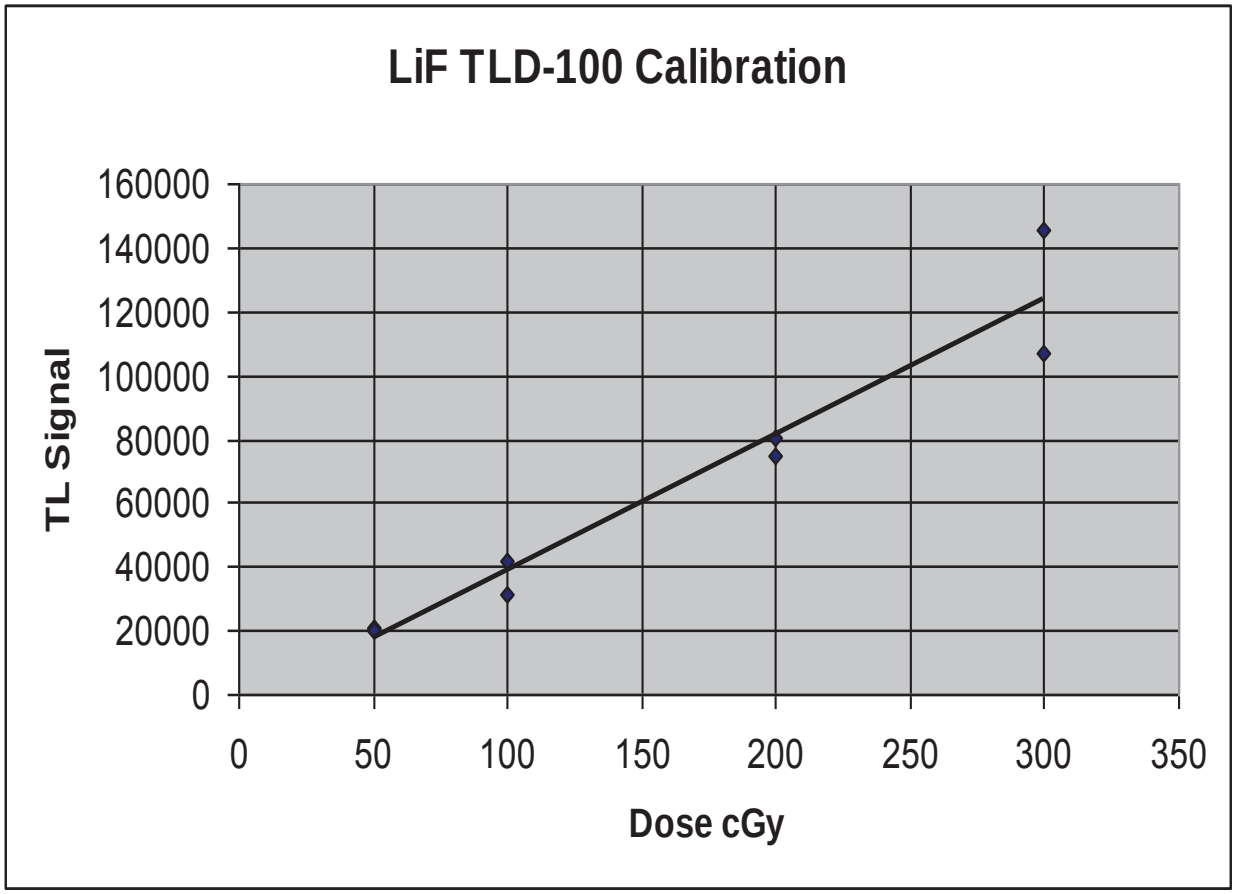

Fig.3: Calibration curve for LiF TLD-100 chips

2. Patient dose measurement

2 $CaSO_4$ dosimeters were used one at entrance and another at exit position of the central axis of a 10 cm x 10 cm treatment field of the telecobalt machine of the Center. Measured doses revealed a 40% change in the dose values at these two positions, which is in agreement with hand calculations. Figs. 4 and 5 below show the glow peaks with CaSO4:Dy positioned respectively at the entrance and exit positions.

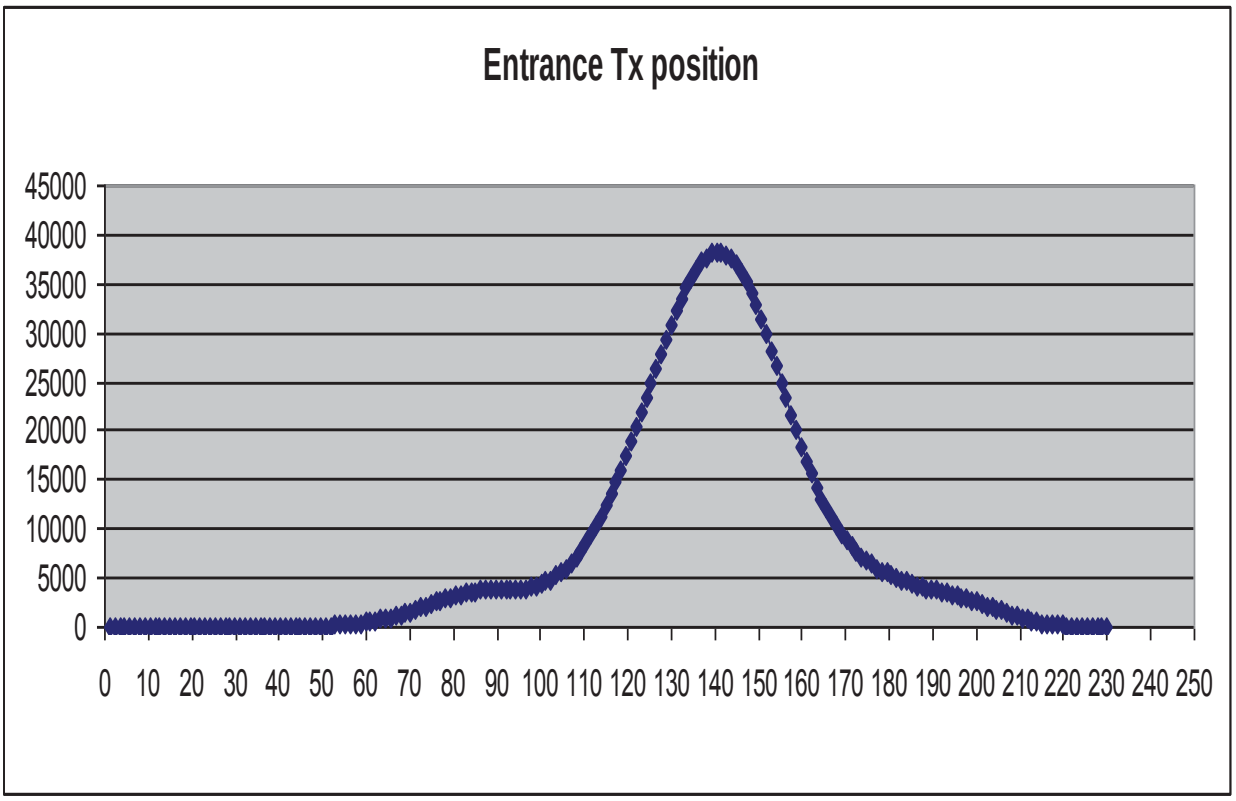

Fig. 4: Glow curve of $CaSO_4$:Dy teflon disc placed at the entrance position

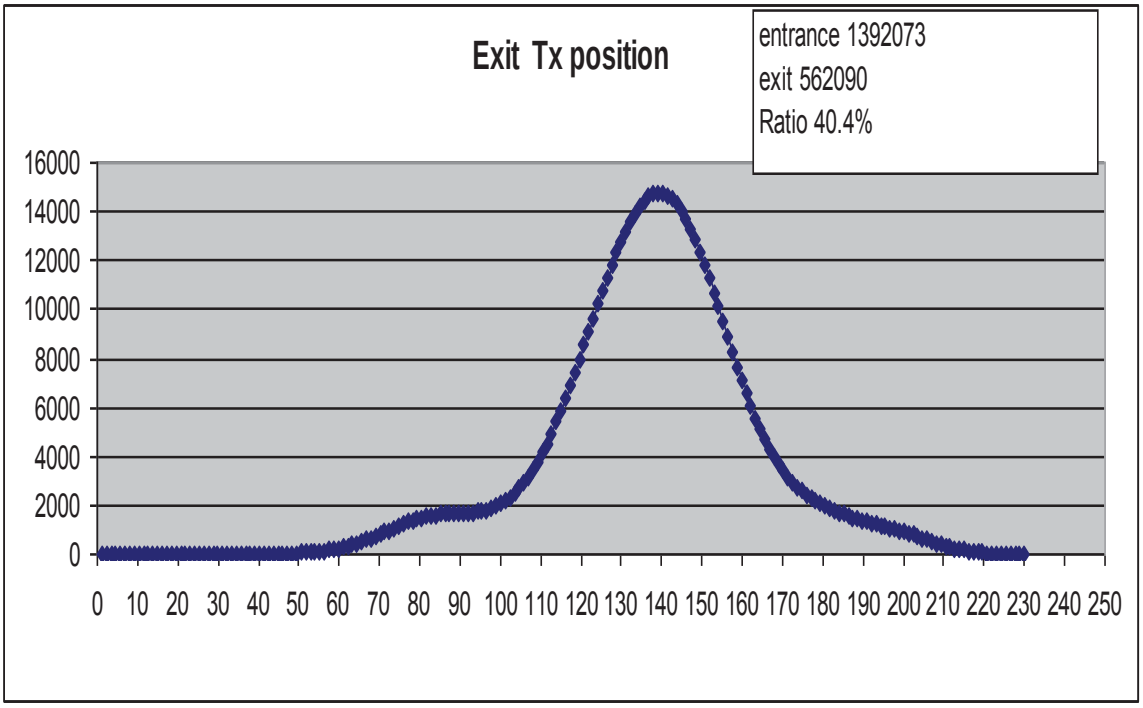

Fig. 5: Glow curve of CaSO4:Dy teflon disc placed at the exit position

3. HDR checks

The ouput of the cobalt HDR machine at this Center was first checked using ion chamber in the HDR calibration phantom by placing the source in the center and the ion chamber with build-up cap at 8 cm. The dose rate was computed using the chamber factors and agreement with previous calibration was observed to be within 2%.

LiF and $CaSO_4$ TLDs were irradiated to a dose of 100 cGy in the HDR machine. The following results were obtained.

With LiF TLD-100 chips

Dosimeter	TL reading	Dose in cGy (from calibration curve in Fig.3)
LiF 1	37113	95
LiF 2	30828	80
LiF 3	28282	74
Average	28282	83
Standard deviation	4545	14 %

With $CaSO_4$:Dy teflon discs

Dosimeter	TL reading	Dose in cGy (from calibration curve in Fig.2)
S1	318578	173
S2	224062	121
S3	259745	141
Average	267462	145
Standard deviation	47728	17 %

Note: Deviation of measured dose from the calibration curves established in these experiments is large as compared to the standard dose to which the dosimeters were exposed. Repeat experiments have to be conducted for better results.

The LiF detectors showed lower response by nearly 15%. This could be due to differences in position of the detectors in the placement in the cavity. A 0.5 cm variation in distance could result in 12% variation. In view of the energy response CaSO4 is reading larger than 100 cGy.

4. Mammography

TLDs were used to measure dose from the Siemens mammography machine at this Cancer Center. Three dosimeters were placed on the breast phantom and an exposure was made. Also the dose was measured using Xi chamber from Unfors Inc. The Xi chamber measured an entrance dose of 1.5 cGy for a setting of 27 kV exposure (auto 123 mAs, 1.1mGy).

The three readings in each case were consistent within 3%.

The dose calculated from calibration curves were 1.05 cGy for LiF and 1.93 cGy for CaSO4 respectively. For CaSO4 higher response is expected at this energy in view of its higher effective atomic number and predominant photoelectric effect at this photon energy. Also the differences seen between the dose estimates with TLDs and the Xi chamber could be due to (a) positional differences between the chamber and the TL dosimeters and b) the calibration plots used are for much higher dose ranges. Repetition of the experiments with careful planning of the experiments is needed.

Acknowledgements: Authors thanks are due to members of physics team namely Messers Fenedit Yesuraj, DhanaSekharan, Srinivasa Reddy, Madhusudan, Shamsuddin and Haritha, at this Cancer Center for carrying out of the above experiments in short time. Also, the dedication and help of Mr. Lakshminarayana of Nucleonix is greatly appreciated. Thanks are also Mr Ramakrishna Rao, Chief Medical Physicist for irradiating the $CaSO_4$ discs in their telecobalt beam.